Doctoral Thesis

Building Shape Classification

submitted in satisfaction of the requirements for the degree of
Doctor of Science in Civil Engineering
of the Vienna University of Technology, Faculty of Civil Engineering

---

Dissertation

Gebäudeform Klassifizierung

ausgeführt zum Zwecke der Erlangung des akademischen Grades eines
Doktors der technischen Wissenschaft
eingereicht an der Technischen Universität Wien, Fakultät für Bauingenieurwesen
von

Dipl.-Ing. Philipp Jurewicz
Matrikelnummer 9726081
Friedrich-Kaiser-Gasse 81/2, 1160 Wien

Betreuer: Univ. Prof. Dipl. Ing. Christoph M. Achammer
Interdisziplinäres Bauprozessmanagement
TU Wien, Karlsplatz 13/234-2, 1040 Wien

Gutachter: Ao.Univ.Prof. Dipl.-Ing. Dr.techn.Christian Kühn
Institut für Architektur und Entwerfen
Forschungsbereich Gebäudelehre und Entwerfen
TU Wien, Karlsplatz 13, 1040 Wien

Gutachter: Prof. Zygmunt Pizlo
Falmagne Endowed Chair in Mathematical Psychology
Department of Cognitive Sciences
University of California-Irvine

Wien, ____________ ______________________________ *This page intentionally left blank*

Building Shape Classification

Doctoral Thesis

Philipp Jurewicz

2023

Abstract

Building Shape Classification

We define the term *Building Shape* within a context of retroactive classification of building collections. We identify that there is a certain complexity present. We aim to find a lean system that can describe a Building Shape with a small amount of meta data. This thesis consists of a theory, a software implementation of major parts of the theory, empirical data as a reference, and a validation of the implementation against the empirical reference.

In an interdisciplinary approach, we investigate how Cognitive Science handles complex data in its domains. Generative Linguistics will provide input for a data structure and an analytical model. The research field of Visual Perception will provide a foundation for the shift from a quantitative towards a qualitative meta data classification model. The qualitative approach will ease some of the complexity challenges. We identify that cognitive concepts like vocabulary, lexicon, implicit statements, syntactic trees, and recursive rules are candidates that can bring structure to architecture meta data.

We introduce four concepts, that are custom tailored to the research task of Building Shape classification: *Classification Sets*, *Weak References, Periphrase* and *Syntax Tree.*

Classification Sets are identified groups of building shape properties like curvature, tilt or proportions. *Weak References* are “Named Relationships” and aim to allow flexibility within one Classification Set. *Building Shape Periphrase* deals with the building shape of a single distinct building part. The interdisciplinary connection back to Visual Perception provides foundations. *Building Shape Syntax Tree* deals with building shapes that are composed of two or more distinct building parts. Its data model is inspired by Generative Grammar from linguistics and is a binary tree structure. A Building Shape Syntax Tree connects multiple Building Shape Periphrases.

A building shape of one building can be expressed in the new data model. Multiple buildings can be compared with each other. We can calculate a numeric score that represents the similarity of two building shapes.

To verify that the theory and its software implementation are producing useful similarity values, there is a test against empirical data that serves as a reference. We look on 80 World Exposition pavilions. An empirical data set was produced by 52 participants. We map the empirical data onto the calculated data to provide quantitative insights. The performance of the whole system, as well as of the four core concepts, is investigated.

The closing discussion part interprets the findings and performs a verification of the hypothesis. It connects the theory back into a broader research picture and shows potentials and possible next steps.

Abstract in German Language / Abstract in deutscher Sprache

Gebäudeform-Klassifizierung

Wir definieren den Begriff *Building Shape* – hier als *Gebäudeform* übersetzt[1] – im Kontext der rückwirkenden Klassifizierung von Gebäude-Sammlungen. Wir stellen fest, dass eine gewisse Komplexität vorhanden ist. Ziel ist ein schlankes System, welches Gebäudeformen mit einer geringen Menge an Metadaten beschreiben kann. Diese Doktorarbeit besteht aus einer Theorie, einer Software-Umsetzung wichtiger Teile der Theorie und einer Validierung der Software-Umsetzung mit Hilfe empirischer Daten.

In einem interdisziplinären Ansatz untersuchen wir wie die Kognitionswissenschaft mit komplexen Daten in ihren Domänen umgeht. Generative Linguistik trägt eine Datenstruktur und ein analytisches Modell bei. Das Forschungsfeld der Visuellen Wahrnehmung trägt eine Grundlage für den Wechsel von einem quantitativen hin zu einem qualitativen Metadaten-Modell bei. Der quantitative Ansatz löst einige der aus der Komplexität resultierenden Herausforderungen. Wir stellen fest, dass kognitive Konzepte wie Wortschatz, Lexikon, implizite Aussagen, Syntaktische Bäume und rekursive Regeln, geeignete Kandidaten für eine Verbesserung von Architektur-Metadaten sind.

Wir führen vier Konzepte ein, die maßgeschneidert für die Forschungsaufgabe der Gebäudeform-Klassifizierung sind: *Klassifizierungs-Mengen*, *Untergeordnete Referenzen*, *Periphrase* und *Syntaxbaum*.

Klassifizierungs-Mengen sind identifizierte Gruppen von Gebäudeform-Eigenschaften wie Krümmung, Neigung oder Proportionen. *Untergeordnete Referenzen* sind Verbindungen mit semantischer Bedeutung und versuchen Flexibilität in Klassifizierungs-Mengen zu bringen. *Gebäudeform-Periphrasen* beschreiben einzelne identifizierbare Gebäudeteile und bedienen sich aus dem Forschungsfeld der Visuellen Wahrnehmung. *Gebäudeform-Syntaxbäume* behandeln Gebäudeformen, die aus mehr als einem identifizierbaren Gebäudeteil zusammengesetzt sind. Hier ist das Datenmodell ein binärer Baum und ist inspiriert von Generativer Grammatik aus der Linguistik. Ein Gebäudeform-Syntaxbaum verbindet mehrere Gebäudeform-Periphrasen.

Eine Gebäudeform für ein Gebäude kann so in dem neuen Datenmodell ausgedrückt werden. Mehrere Gebäude können miteinander verglichen werden. Wir können einen numerischen Wert errechnen, der die Ähnlichkeit von zwei Gebäudeformen ausdrückt.

Um zu verifizieren, dass die Theorie und ihre Software-Umsetzung sinnvolle Ähnlichkeitswerte produzieren, werden Tests gegen empirische Referenzdaten durchgeführt. Die empirischen Referenzdaten wurden von 52 Teilnehmern bezogen, und konzentrieren sich auf 80 Pavillons auf Weltausstellungen. Wir vergleichen die empirischen mit den errechneten Daten und identifizieren quantitative Differenzen. Sowohl die Leistung des gesamten Systems als auch der vier Kernkonzepte wird untersucht.

Der abschließende Teil interpretiert die Ergebnisse und unternimmt eine Verifikation der Hypothese. Die Diskussion versucht die vorgestellte Theorie wieder in einem breiteren Forschungs-Umfeld zu positionieren. Potenziale und mögliche nächste Schritte werden aufgezeigt.

1 Eine direkte Übersetzung aus dem Englischen ist schwierig; siehe dazu auch Fußnote 54

Acknowledgements

This doctoral thesis was a rewarding academic journey of the mind. It would have not been possible without the support of the following people.

My supervisor Prof. Christoph Achammer made this journey possible, not only by providing the academic setup but also with guidance and insights from his personal knowledge. Inputs like *Alpine Architektur* and thoughts about *Gestalt* made the meetings joyful. His openness to interdisciplinary work is one of the pillars this thesis is build upon. The surprising connections like "Oh I know him. I rehearsed music with him" even to researchers in cognitive science were often just around the corner. The always positive attitude towards the research project helped to overcome doubts and dead ends and let we exit each meeting with fresh motivation.

The empirical part would not be possible without help of the Institute of *Integrale Bauplanung und Industriebau* at TU Wien. Isolde Tastel and Rüdiger Suppin supported the organisational effort. Rüdiger casually asked important fundamental research questions even while moving tables and chairs. The international stages of two *Industriebauseminare* have been important check points during the journey.

This doctoral journey is a sequel, preceded by my diploma journey in 2004/2005 with a related theme on *Building Shape*. The diploma thesis brought me to wonderful Sydney and I returned with my first scientific writings. This time have not been possible without the support of Prof. Vinzenz Sedlak who welcomed me in his research unit at UNSW and introduced we to a new breadth of building shapes and the supporting knowledge.

Travelling costs money and renders out time which otherwise would have been part of my professional obligations. I remember the moment well, when I stepped into a management office at a telecommunication company to confess that I have a big academic side project which will eat up time. In return I received a "Philipp, of course I support you. There is nothing worse then a half-finished dissertation, never to be completed. I have one in my drawer as well."

Lastly many long journeys have detours. And this have had a few big ones. I want to wholeheartedly thank my girlfriend Isolde Rupprechter for all the things she made possible and all the efforts she took to help me find the time to finish the work. The biggest change for us was the founding of our small family with the birth of our son Dante, and the first years of his joyful life. Dante keeps us busy, stressed and delighted.

I remember the wise statement of Prof. Christoph Achammer: "When is the estimated day of birth?"; me: "19th of December"; him: "Okay, you have to finish the research project by 18th of December!". I missed this mark, ... by a few years, but finally I am at the destination point.

Table of Contents

Part I

1. Introduction

Most of the work in architecture aims to create buildings for our physical environment which can serve a specific need. One of the major effects is that buildings define and enclose space by their *form*. Therefore *form* is one of the key terms in the discourse of architects, engineers, clients and the public. This research focuses on *building shape* which is just one aspect of form, but a prominent one.

1.1. Use of Building Shape

Within architecture research not all buildings have the same importance for academic discourse. Architecture theory articles and curated books often single out case studies that are investigated and discussed. Sometimes building collections exceed the limit feasible for print publication. For instance the original "Phaidon Atlas" (Phaidon Press, 2004) contained approximately 1000 buildings for the years 2000 up to 2004. Its successor project was the curated Internet database "phaidonatlas.com" (Phaidon Press, 2015) and it contained 3679 buildings for the years 2000 up to 2015 (as of July 2015)[2]. Other Internet databases that store single buildings like archINFORM claim to index 62000 significant buildings (archINFORM, 2015). These databases are still based on traditional but proven *relational database technology* which is mainly text based. Specialised databases that take visual and spatial data as first class citizens seem to be niche tools in day to day architecture research.

As the size of building collections increases meta data becomes more important to retrieve meaningful results. Various groups of meta data are added to such collections; for instance: architects, engineers, accessibility, building environment, building type (application), location, urban density, elements, material, structure and sustainability. Some of these meta data groups can have independent authoritative sources like the "Art & Architecture Thesaurus" (Getty Research, 2015) or "Findex" (Informationszentrum Raum und Bau, 1981). It seems surprising that building shape as one of the most prominent visual features of contemporary architecture is seldom captured as meta data. It should be mentioned that the archINFORM database does indeed have some building

2 As of 2017 the online database phaidonatlas.com appears to be no longer available to the public any more, and redirects to an other Phaidon publishing site.

shape/form meta data but only ~2.5% (~1510 out of 62000) of the data set is attributed with it.

We can imagine a task that we have to instruct another person to pick a building from a group of candidates, and we are only allowed to refer to its building shape. Figures 1, 2, 3, 4, 5 and 6 show the potential challenges in such a task.

Figure 1: Museu de Arte Contemporânea de Niterói by Oscar Niemeyer (bottom row middle) is easy to identify by its building shape

Figure 2: Museu de Arte Contemporânea de Niterói by Oscar Niemeyer (bottom row middle) is challenging to identify

Why does building shape classification matter? As with all well defined meta data sets tailored for a domain it could be foundational work for possible new insights. These new insights might include: discovery of hidden relationships, better search results in retrieval systems and enablement of further architecture typology work in building design. One possible benefit of building shape classification might be: to communicate complex shapes across parametrized designs and integrate them into Building Information Models (BIM). This could enable the user to find construction detail solutions in earlier buildings.

Figure 3: The Kaleidoscope (bottom row middle) is easy to identify by its building shape

Figure 4: The Kaleidoscope (bottom row middle) is challenging to identify by its building shape

Figure 5: The German Pavilion (bottom row middle) is easy to identify by its building shape

Figure 6: The German Pavilion (bottom row middle) is challenging to identify

1.2. Definition of Building Shape

To define the term *building shape* we can first examine more general definitions of shape and form. We will use the definitions from Rudolf Arnheim from 1954[3] which is in a Gestalt theory tradition. In art and architecture there are many definitions of shape and the Gestalt theory is just one possible source. One reason we use a definition for building shape that derives from Gestalt psychology, is the interdisciplinary connection with cognitive sciences like Linguistics and Visual Perception. Researchers in these sciences investigated findings from Gestalt psychology and used them for some of their own main assumptions.

Arnheim (1974, p. 47) begins his definition of shape by dividing it into two sub types: *physical shape* and *perceptual shape*. For *physical shape* the definition is very crisp and is determined only by the boundaries of an object. For instance "the two surfaces delimiting the side and bottom of a cone". He points out that other spatial aspects like orientation, occlusion and environment context are not included.

The second subtype is *perceptual shape* and of greater interest to Arnheim. In contrast to its physical counterpart it is influenced by many more aspects including spatial orientation and its environmental context. It is also closely linked to human perception:

> "Perceptual shape is the outcome of an interplay between the physical object, the medium of light acting as the transmitter of information, and the conditions prevailing in the nervous system of the viewer [...] The shape of an object we see does not, however, depend only on its retinal projection at a given moment. Strictly speaking, the image is determined by the totality of visual experiences we have had with that object, or with that kind of object, during our lifetime." (Arnheim, 1974, p. 47)

Later Arnheim provides a short quote by the painter Ben Shahn: "Form is the visible shape of content". This is the first sentence to a whole chapter dedicated to *form*. He states that this sentence is a good formula to distinguish between *form* and *shape,* and elaborates on the connection of the two:

> "Only for the sake of extrinsic analysis, however, can shape be separated from what it stands for. Whenever we perceive shape, consciously or unconsciously we take it to represent something, and thereby to be the form of a content" (Arnheim, 1974, p. 96)

In architecture, form might include aspects like geometry, aesthetics, material and structure. Various subdisciplines in architecture and civil engineering often focus on one or two of these aspects but can still communicate with each other due to the common concept. For instance architecture theory often looks into the "content" of a single or a

3 The Bibliography references the year 1974, because we use the "1974 expanded and revised edition with some new illustrations, of the original publication of 1954"

few buildings. Dedicated case studies can include a historic perspective, social implications, fashion trends and much more.

Arnheim's distinction between form and shape will be utilised in this thesis. It allows to look at shape in separation from other aspects and perform analysis. We will additionally constrain his term of *perceptual shape* to the domain of architecture. Only the outer visible parts of buildings are considered. We will include aerial images but interiors, occluded parts or technical drawings will be omitted. Also the topic of transparency which is often of interest in the architecture community will be omitted to keep the scope of this thesis manageable.

The distinction between shape and form in architecture is by no way new to this thesis but a known analytical method. For instance Alexander describes it in an analogy with geometrical shape:

> "The shapes of mathematics are abstract, of course, and the shapes of architecture concrete and human. But that difference is inessential. The crucial quality of a shape, no matter of what kind, lies in its organization, and when we think of it this way we call it form" (Alexander, 1964, p. 134)

By following Arnheim we first have to solve a dilemma: He is very strict about: "a shape is never perceived as the form of just one particular thing, but always as that of a *kind* of thing". For example one specific instance of a fork has the shape of a kind of fork. And many forks can have the same kind of shape. This opens the definition of shapes to classification and categorization. This is positive as this is one of the objectives of this thesis. But the problem with most buildings is that they are usually *unique* because they are expensive to erect, typically can't be moved and therefore must take their spatial and environmental context into account[4]. So, is it not possible to have a perceived building shape and be able to compare building shapes with each other? Is this only possible with geometric *physical building shape* and a comparison based on 3D mathematics?

Because of the uniqueness of many buildings we can solve this dilemma in two ways. On the one hand we could concentrate by looking at smaller solid geometric primitive that are repeating shapes. For example a cube or a cone might appear in many buildings as one distinct building part which can be correlated with others. The other possibility is to concentrate on features that are essential to the identity of a building. These features are qualitative topics like curvature, arrangement or proportions. The instance of a feature within a building is a repeatable stereotype and a property of it. So a building with tall

4 Of course there are buildings that do not conform to this simplified view: There are row houses that have many instances; there are temporary buildings which can be moved, etc. As mentioned before: not all buildings are of same interest to architecture discourse. Also within architecture there is a stereotypical positively perceived expectation that a building design is a creative answer of a team to all the requirements, constraints and limits of a construction task. This creativity often leads to different physical geometries and perceived building shapes.

proportions and an anticlastic surface curvature could be correlated through theses features to a different building with similar proportion and an anticlastic curvature. We can sum up the similarity of various features to have an aggregated similarity of the building shapes. We will take this second approach.

Features can be bundled into groups like the above mentioned curvature, arrangement or proportions. To some degree, these groups can be evolved and discussed in isolation. This independence makes it easier to reason about them.

We will also try to be interdisciplinary and allow influence from another definition of 3D shape which recently gained some traction in the Vision[5] research community. While Arnheim concentrates on analysis of art and architecture, Pizlo and his colleagues have a different objective: They concentrate on the *perception* of shape by humans or computational models that simulate human perception.

> "Understanding shape perception is of fundamental importance. Why? Shape is fundamental because it provides human beings with accurate information about objects "out there." Accurate information about the nature of objects "out there" is essential for effective interactions with them. An object's shape is a _*unique*_ perceptual property of the object in the sense that it is the _*only*_ perceptual property that has sufficient complexity to allow an object to be identified. Furthermore, shape's high degree of complexity makes it quite different from _*all*_ other perceptual properties. [...] Shape is unlike all of these properties because it is much more complex. An object's shape can be described along a large number of dimensions." (Pizlo, 2008, p. 1)[6]

To achieve their goal to write a computational model that simulates human vision the researchers redefined what they mean by shape. They first split up their definition of shape into two parts: an *analytical definition* and an *operational definition*[7]. Their analytical definition differs from Arnheim's definition:

> "Shape is an intrinsic characteristic of an object because it refers to its self-similarity, rather than to the similarity of one object to another." (Pizlo *et al.*, 2014, p. 9)

We can see that *building shape for classification* does not fit in Pizlo's definition because we actually *want to compare* buildings. But the above definition lifts Arnheim's burden that shape is only present when there are many instances of objects that share a kind of shape. This thesis will assume that a building, even if unique, has actually a building shape but for the calculation of shape similarity we will use smaller features. At the end we sum up the smaller features and can numerically express the similarity of two building shapes.

5 We will use the term *Vision* as the sibling-term of *Linguistics* when we reference these two research domains. See also the Glossary chapter 2.

6 Underscores "_" added to emphasis the italic font used in the original version

7 We will discuss Pizlo's approach in more detail in chapter 5.3.4.

Even though this alternative definition from Pizlo sounds contradictory to Arnheim's, it will be shown later that it is actually also driven by constraints that can be associated with some of the Gestalt Psychology assumptions. The relations between the two definitions should be seen in a historic context. Arnheim wrote his definition in 1954 in a time where Vision research was evolving.[8]

We arrive at the following definition:

Building Shape is the outer visible appearance of a building as perceived by an observer. It can be described by its essential spatial features. It is not a pure geometric 3D model and features that describe it can come from different domains, not only geometry. It is just one of many aspects of *building form*.

Above definition contains the phrase "as perceived by an observer". This means that shape will not be used in a way that is construction-focused. Please be aware of this perspective change. Especially readers that have an architecture background might instinctively concentrate on the construction phase of a building.

Sometimes it is insightful to not only define a term but also its opposite. Pizlo and his colleagues did this for their hypothesis:

> "A big problem emerges as soon as you realize that we know that there are patterns and objects that actually have no shape at all. [...] A crumpled piece of paper, a bent paperclip, or a rock before it is shaped by a human hand do not have what we really mean when we refer to an object's shape. All these objects [...] are called _*amorphous*_ or _*shapeless*_. Why? They are amorphous because they are completely irregular. Some regularity is missing. [...] This observation makes it clear that the term shape makes reference to some spatial regularity, or some self-similarity possessed by an object." (Pizlo *et al.*, 2014, p. 7) [9]

They assume that the desired spatial regularities are present in "most, probably even all, living organisms and to inanimate objects that serve useful functions" (Pizlo *et al.*, 2014, p. 13) We will not follow their definition of *shapeless* but it is a good indicator where we will hit edge cases when we try to create a classification for constructed building shapes. Amorphous and highly irregular buildings have been build. We should aim to find a system that is able to cover them, at least to some degree. In their creative process architects might chose such irregular building shapes as a deliberate design decision to challenge the users of their building to experience space in new ways. A few outlier buildings do hopefully not invalidate the whole system.

8 Arnheim hatches: "In visual experience we observe only the results of this organizing process. Its causes must be sought in the nervous system. Of the exact nature of such physiological organization, next to nothing is known"(Arnheim, 1974, p. 68).

9 Underscores "_" added to emphasis the italic font used in the original version

1.3. Scope and Chapter Overview

This thesis consists of the following blocks:

- a theory
- a software implementation of major parts of the theory
- empirical data as a reference
- a validation of the implementation against the empirical reference

The developed theory is driven by interdisciplinary input and is spanning most of the text based chapters. The author is in the fortunate position to be able to write the full software implementation by himself. He currently works as a professional software engineer but has his educational background in architecture. The topic of building shape classification is mainly a subject matter challenge. Though it is also a software engineering task. The software will handle classification with a custom data structure. Writing software is a time intensive but rewarding task, as one can see a theory become executable and verifiable. Even though it was a big effort, the software implementation is mostly invisible in the text part of this publication and is documented at a high level in Appendix E (19.5).

The following is a brief overview of the main chapters:

- Part I – contains: 1. Introduction, 2. Glossary, 3. Related Work and 4. Research Question. We identify that there is a certain complexity present when we work with building shape and that we should accept and handle this complexity.
- 5. Interdisciplinary Approach – We will start with an interdisciplinary approach by investigating how other fields handle complex data in their domains. Linguistics will provide input for a data structure and an analytical model. The research field of Vision will provide a foundation for the shift from a quantitative towards a qualitative meta data classification model. The qualitative approach will ease some of the complexity challenges. We will also look how other researchers from architecture approached the problem of classification.
- 6. Classification Overview – is a high level introduction of three core concepts of the theory. The idea is to give the reader the big picture first and following chapters will go into sometimes lengthy details. We will see which classification sets are selected and which are omitted. Each selected classification set is introduced with a few sketches accompanied by example photographs, so the reader can get familiar with them. This is followed by a brief introduction to the two concepts of *Periphrase* and *Syntax Tree*.

- 7. Building Shape Periphrase – is a detailed chapter which deals with the building shape of a single distinct building part. Each of the ten classification sets are explained in detail and the connection back to Vision provides foundations.
- 8. Building Shape Syntax Tree – is a detailed chapter which deals with building shapes that are composed of two or more distinct building parts. The data model is inspired by Generative Grammar from Linguistics and is a binary tree structure. It can connect multiple Periphrases from the previous chapter into one computational model.
- 9. Comparing Building Shapes – utilises the data structures from the previous two chapters which represents one building shape of one building and allows to compare it with an other one. This chapter will also introduces the forth core concept of *Weak References* as an application of *Named Relationships*. It is best explained while comparing building shapes. At the end we have a numeric score that represents the similarity of two building shapes.
- 10. Examples of Building Shape Comparison – takes the theory from the previous chapter and applies it to real building examples. We can see how the implicit and explicit values from the Periphrase are merged and how the classification matches traverse the binary tree structure. While they bubble up they are altered by rules at various nodes. At the top we will sum up all the values and have a similarity value for each example pair.
- 11. Empirical Data Gathering – To verify that the theory is producing useful similarity values there is a test against empirical data that serves as a reference. We will look on 80 World Exposition Pavilions. The empirical data set was produced deliberately for this thesis and had 52 participants in multiple data gathering sessions.
- 12. Discussion of Empirical Benchmarks – We will see how the computed data and the empirical data are mapped to provide quantitative data. The performance of the whole system as well as the four core concepts that make up the system are discussed. Even the performance of single classification sets can be discussed and their impact measured. Interesting data points are singled out and interpreted.
- Part III – contains: 13. Discussion / Findings, 14. Potential, 15. Next Steps and 16. Closing Remarks. The discussion part interprets the findings and performs a verification of the main hypothesis and sub-hypothesis. It tries to connect the theory back into a broader research picture and shows potentials and possible next steps.

The various appendixes document the input data, expose more empirical data in tables and explain the software implementation.

1.4. Insights vs. Probabilities

This research is trying to find a smart and lean system that can describe a building shape with a small amount of meta data. The goal is to create a foundational system that can be used as classification meta data on building collections. Empirical data that was gathered for this research is used to validate the proposed system. Comparing the computational results from the software implementation with the ranking of building shape similarities performed by human participants is an important part but not the main goal.

When empirical data is present it is tempting to also use it with new trends like *machine learning* and *probabilistic statistics*. But for such statistics systems the quantity of empirical data is an important factor. Different to the massive data sets available for e.g. Natural Language Processing or Computer Vision, this quantity of data is not available for a topic like building shape. This might change in the future, but even then there is a need to start somewhere. A *hybrid* system that use *internal insights* combined with the *external observation* data might be a good path forward. Ideally the contributions of this thesis might help such future efforts.

2. Glossary

This thesis is intended for a building science audience, therefore we will clarify the use of some terms to minimize ambiguity.

- *Building Shape* – is the outer visible appearance of a building as perceived by an observer. It can be described by its essential spatial features. It is not a pure geometric 3D model and features that describe it can come from different domains, not only geometry. It is just one of many aspects of *building form*. The definition is discussed in the introduction chapter 1.2.
- *Classification Item* – is either a text keyword or a *sketch* that can be used to index a *building shape*. It is usually grouped with related items in a *classification set*. Classification items have a technical name. This technical name is typical in a “camel case” style and has a light grey background colour like curvatureConvexConcave.
- *Classification Set* – a group of classification *items* that have common properties. Classification sets are related to custom tailored domain vocabularies. For example: all *items* that describe *curvature*. We write them with a capital first letter when we reference them as a set, like “Curvature”. There are sixteen classification sets: Angle-Plane, Angle-View, Edge-Plane, Edge-View, Tilt, Texture, Curvature, Feature, Lattice, Proportions, Spacing, Cardinality, Orientation, Relative Size, Size Randomness, Variety.

- *Distinct Building Part* – A building can consist of one or more distinct building parts that contribute to its identity and potentially further less important parts. The parts can be identified by an observer and have a *building shape*. See chapter 6.1
- *IL 22* – Is an abbreviation for the book publication “IL 22 - Form” (Otto, 1988). It is a publication from the “Institut für leichte Flächentragwerke” (IL) / Institute for Lightweight Structures headed by Frei Otto. The book is part of a series: IL 21 up to IL 25. See chapter 5.4.2
- *Ontology* – is only used in its technical meaning as a standardised data model like within the Web Ontology Language (OWL). The use in philosophy and theory is different and not covered here.
- *Parallel Architecture* – Refers to a specific linguistic system of that name by Jackendoff. The word “architecture” in this term has no direct connection to an architecture that is concerned with buildings. See chapter 5.1.2
- *Periphrase* – The term is borrowed from Language Science and is used as the name of one the major concept introduced in this thesis. It defines the *building shape* of one *distinct building part*. It groups ten slots of different *classification sets* and these sets use *qualitative features* and circumlocution (which is a synonym for Periphrase). See chapter 7
- *Qualitative Feature* – This term is also often used in Vision research and describes the fact that something can be identified by a property that can exist without any quantifier. For instance concave curvature versus convex curvature.
- *Quantitative Feature* – This term is often used in Vision research and describes the fact that something can be identified by a measurement like a metric unit or an angle. For example one object is twice as long as a reference object.
- *Recursion* - “in which the solution to each problem depends on the solutions to smaller instances of the same problem”(Graham, Knuth and Patashnik, 1994). In computer science and in this thesis we use the term *Recursion*. In mathematics, like in Grahams definition, the term *Recurrence* is also widely used.
- *Sketch* – is used as a convenient grouping of any visual representation and includes drawing, rendering, diagram and icon.
- *Syntax Tree* – A binary tree data structure that can be used to describe the spatial arrangement of two or more *Periphrases*. It is inspired by related tree structures from Linguistics. When necessary it is prefixed as *Building Shape Syntax Tree* to disambiguate it from its Linguistic counterparts. See chapter 8

- *Vision* – Is not used in the meaning of a creative act or thought, but as part of the Cognitive Science of *Visual Perception* that deals with theory and empirical practise of how humans see with their eyes. We additionally include *Computer Vision* research which tries to create models that simulate human visual perception. “Vision” is also the title of a seminal publication in the domain by David Marr (1982) See chapter 5.3. We will use *Vision* as the sibling-term of *Linguistics* when we reference these two research domains. We will often encounter terms like *Vision research*.

3. Related Work

We want to look at prior research from two points of view: First, existing projects for shape description and classification that might be applicable for buildings. Second, the interaction between Architecture and Cognitive Science – especially Linguistics and Vision – when it comes to structuring of information.

Two approaches to shape classification that originate in architecture and civil engineering have dedicated chapters. The publication “IL 22 – Form” (IL 22) by Frei Otto and his team at Stuttgart University in chapter 5.4.2. The digital Structural Design Aid (SDA) with its *typology of shape* in chapter 5.4.3. They are preluded by a brief discussion about architecture content and building context based on publications from Christopher Alexander in chapter 5.4.1. Alexander’s overlap with language is discussed when we look into Linguistics in chapter 5.1.

Researchers from design domains already recognised similarities in their mind models with work done in cognitive science. “The Logic of Architecture” (Mitchell, 1990) uses a simplified language syntax example as an analogy to introduce *procedural rules* for architecture. These rules can create and recognize classical order in columns and can recreate Palladian villas. The classical order example could also be connected with cognitive science from Marr and Nishihara (1978) who propose that hierarchical reduction is a basic function of human vision and perception. Alexander (Alexander, 1964, p. 7) is also embracing Logic to tackle the design process, but Mitchell’s work is closer to be implementable in software by defining stricter rules and constraints.

Mitchell’s work on Palladian villas is based on a collaboration with Stiny (1978). In retrospective Stiny (2006, p. 19) explicitly confines his work on *shape grammar* from linguistic grammar. He admits that there seems to be overlap, as both use combinatorial operations but he did not mange to find a convincing broad common ground.

Shape grammar based approaches have a 2D or 3D representation at their core and are trying to find formal and logical rules to define advanced shapes in general. *Procedural architecture* can be based on shape grammar approaches. Contributions like “Instant Architecture” (Wonka *et al.*, 2003) and “Procedural Modelling” (Müller *et al.*, 2006) describe how soft architectural rules must be technically captured and taken into account to describe not only shape in general but *building shape*. It is possible to define these rules in technical Domain Specific Languages (DSL). Commercial software products for urban planing and the entertainment industry like “CityEngine” were enabled by these contributions. When the soft architecture rules are omitted even a lay observer sees that something is wrong with the presented buildings. For instance windows are at locations that are really unusual, proportions are not balanced or axis in the compositions are odd.

Fuzzy shapes (Zhang, Pham and Chen, 2002), (Zhang, Pham and Chen, 2004) can be stored and retrieved in a specialized fuzzy shape database. The system requires that the information must be present in a custom data format and use superquadrics as the main geometry primitives. Superquadrics are also known as superellipsoids and supertoroids. They can morph into numerous shapes by altering the mathematical parameters that define them. So there is a path how to transition as well as how to relate different shapes.

The research team was mainly focused to find a way to created digital tools that can help designers in an early design stage where quantitative values like exact measures and correct arrangements are not yet important, but will become necessary once the design process progresses.

> Superquadric 3D models proposed by Barr [2] use several shape parameters to quantitatively define a shape, yet each shape parameter is directly related to one quality of the shape such as squareness/roundness and size. Hence superquadrics is both quantitative and qualitative. Such a property makes superquadrics the ideal candidate for bridging qualitative conceptual shape design at early stage and quantitative detail design at later stage. (Zhang, Pham and Chen, 2002, p. 3)

The research team opted to use use a Constructive Solid Geometry (CSG) approach for the composition of multiple superquadrics.

The flexibility of superquadrics made them also attractive to Vision researchers like Dickision and Pentland(1992), who are mostly interested in the qualitative aspects. In Vision research it is assumed that the quantitative aspects are less well handled by the human perception system.

Building Information Model (BIM) systems are usually based on Constructive Solid Geometry (CSG) and are therefore related to shape grammar and fuzzy shape. The use case for BIM is about interoperability and precision within large scale construction projects. Usage of BIM systems grows. These systems also store an increasing amount of domain expert knowledge in digital format. It might become of commercial value to retrieve this hidden knowledge from a repository of past project. Query by *building shape* might be one desired novel method.

Fuzzy shapes, shape grammar, and Constructive Solid Geometry represent valid approaches to describe building shape. They have a slightly different definition of “shape” which is closer to geometric and physical shape. This is of course acceptable as it helps them to achieve their goals. Though this thesis proposes an alternative. It does not involve 3D model creation at its core. Rather building shape classification is based on text keywords and sketches that describe qualitative visual features. By not having a 3D model at its core it might be possible to reuse advanced tools and techniques from computer science and computational linguistics in building science.

Operative Design (Di Mari and Yoo, 2012), (Di Mari, 2014) take a related approach to this thesis. It works with a classification that is a mix of text language elements like *verbs* and 3D diagrams/sketches to introduce a design process language for architecture education.

The Vision researcher Biederman 1987 introduced a “Recognition-by-Components” theory. It contains primitives called *geons*. We will have a broader discussion about this contribution in chapter 5.3.2.

“Space Syntax” by Hillier and Handson is not considered in this thesis. Similar to Alexander’s “A Pattern Language” it deals with structured and analytical approaches but does not have the task of building shape classification and comparison at its core.

"ShapeNet: a richly-annotated, large-scale repository of shapes represented by 3D CAD models of objects. ShapeNet contains 3D models from a multitude of semantic categories and organizes them under the WordNet taxonomy[10]." The research effort around ShapeNet is not considered for this thesis. This has two reasons: First; type of data - Even though the scope of ShapeNet is very broad, it currently contains mainly 3D models that are "available". These are in most cases smaller objects like f.i. chairs (6778 objects in 23 WordNet categories) or objects which are of interest for military, the gaming industry, or gaming enthusiast like f.i. air-planes (4045 in 11 WordNet categories). Objects which are related to buildings are mostly items to *decorate* a 3D scene to make it alive. Buildings as a whole seem to be absent at the moment. Second; one goal of the ShapeNet project is to annotate 3D data. Objects can be successfully categorized as a chair and then potentially nested into the WordNet chair taxonomy "chair => armchair => Morris Chair". Therefore WordNet is the limit of the potential category depths. There is no annotated description of the shape properties themself. For ShapeNet this is not necessary, because the 3D data is available for further geometric analysis by associated research projects. ShapeNet can use the traditional definition of shape, with the “a kind of chair” association. But as discussed further above these “a kind of ...” associations are mostly absent in contemporary buildings.

10 “WordNet is a large lexical database of English. Nouns, verbs, adjectives and adverbs are grouped into sets of cognitive synonyms (synsets), each expressing a distinct concept.” by Princeton University. WordNet is a general purpose database with no special focus for shapes.
Christiane Fellbaum (1998, ed.) WordNet: An Electronic Lexical Database. Cambridge, MA: MIT Press.

4. Research Question

4.1. Meta Data

Architecture researchers might have access to specialized databases that index the data and allow retrieval of individual buildings. Often text based classification allows to retrieve buildings by different aspects and research interests; for instance by application or country. Sometimes all text based classification is collapsed into a single set of keywords, due to technical reasons and simplification. When the user requests that many keywords need to be present in such a database system, a query result set might contain very few or zero matches. Desired results might be omitted because they do not match a less important but still required text keyword.

On the other hand there are commercial search engines like Google Image Search. As of 2021 search engines allow mainly text search terms to be supplied to retrieve search results. If one supplies to many search terms the ranking in the result set quickly gets polluted by matches from other domains that just happen to use the same words in text close to an image. The user has to add additional search terms to stay within the architecture domain (for instance "contemporary architecture" plus a geometric term like pyramid, sphere, etc.)[11]. Norvig (2017) points out that the methodology behind Google search product are trained probabilistic statistics and not lean smart explanatory theories.

In many contemporary architecture buildings the building shape is complex. This complexity seems to be intended by the executing architects as part of their creative design. As a researcher in architecture one can either simplify this complexity of building shapes into terms like *free-form* or try to accept and handle it by applying advanced but more labour intensive classification.

Simplification to single terms like *free-form* or *boxes* bears the disadvantage that they quickly become buckets for "any other building shape". Buildings end up in this groups together, but when compared with each other they might have very different building shapes.

Text keywords are in their most simple implementation an unsorted group of words. More careful system will try to create closed sets, so it is easier to apply more then one keyword without confusing the user. Further work can be done by arranging the key-

11 As of 2021 a recent addition by search engines like Google Image Search is the "search by example" where the user can select an image from a previous images search and get the results that an algorithm has identified as related. The results seem to be a mixture between 2D photograph similarity and related full text data and seem not to contain special shape analysis.

words in purely hierarchical taxonomies which obey rules for membership and can express exclusiveness. If the keyword set itself is organised in an *object graph* then technical tool like the Web Ontology Language (OWL) can help. Examples for such groupings for building shapes can be found in earlier work by the author (Jurewicz, 2005).

As the domain for this research is architecture one might argue that there is no need to give every classification item a distinct text name but a *sketch* (see also Glossary) might transport the information as well. These *sketch only* classification items can be grouped in classification sets, otherwise they might become ambiguous. When used in traditional database system these sketches still need some textual or numerical identifiers for technical reasons, but this can be an arbitrary name. Sketches tend to work well in communication with individuals of different languages. Sketches, drawings and renderings of all kind play a significant role in architecture and are a central topic in architecture education as well.

One simple counter measure to avoid the drawbacks of simplification into a single term is to apply multiple keywords to a building shape. When the applied keywords themselves are not further organized it becomes hard to judge for a user which of these keywords are important. This becomes even more apparent when spatial composition is present. Contemporary buildings often consist of more then one distinct building part and have spatial compositions and arrangements.

4.2. Adaption of the Hypothesis

At one point the research question of this doctoral thesis was adapted significantly. This adaption enabled the integration of a few new insights.

There was a base assumption that composition, or at least hierarchical geometric transformation, is present in most building shapes[12]. The initial hypothesis focused on one concept from Generative Linguistics: *syntactic binary trees* as a tool to handle data hierarchies well.

Initial hypothesis: It is possible to overcome shortcomings in building shape classification of traditional architecture databases (like the gap between shape stereotype and final building shape) if one adapts the pattern of binary syntax tree from the discipline of Generative Linguistics and uses the pattern in the context of architecture. Such a system performs better then the use of keywords.

12 Vision researchers like Biederman (1987) also made this assumption that composition is ubiquitous but their primitive building blocks were different. See chapter 5.3.2.

The software implementation was started in anticipation that a catalogue of shape stereotypes would emerge.[13] Expected stereotypes would be for examples: vault, dome, cylinder, etc. It is possible to describe a generic shape stereotype like a vault as a binary tree of transformations. For example: a cylinder with a horizontal orientation and a truncation at the lower part can be a stereotypical vault. These stereotypes could then be used as a benchmark with a system that just uses keywords. So a binary tree that *describes a vault* would be compared to a *text keyword vault*. The binary tree should have the advantage that it can be further investigated and split up by the software, while the text keyword can not.

The designated set of buildings for the empirical comparison have been 80 World Exposition pavilions. These buildings have been analysed and the binary tree meta data as well as the text keywords identified. This manual process was done by the author by investigating photographs and creating technical meta data files. Though this procedure turned out to be surprising. No broad set of stereotypes based on mathematical geometries did emerge in the 80 World Exposition pavilions.[14]

The following pattern have been observed:

- The keywords that did emerge used wording that often described *qualities* rather then *quantities*. The words are often shared with mathematical geometry terms but have slightly different meaning. For instance the definition of a right angle in architecture is usually a bit more tolerant and a 92 degree angle would be considered OK, due to the experience from real world buildings.
- The use of *symmetry* and *axis* of the whole building was less dominant then anticipated during perception.[15]
- Architecture space behaves different to geometry space. A significant difference is that architecture space is constraint by the presence of *gravity*. While we can freely rotate and stretch geometric objects in geometric space many of these transform-

13 The assumption was to identify and filter down to a group of geometric bodies. The plan was to follow the way architecture and entertainment industry 3D software usually works. One starts with a primitive, then changes its identity by manipulating vertices and edges, changes its overall proportion, and maybe add some transformations that are applied to the whole model by manipulating its bounding box. (lattice). Usually these primitives are: box, sphere, cylinder, cone, pyramid, torus, regular triangular prisms and regular polygons prisms. An alternative way to create the initial shapes in 3D software is from extrusion of 2D lines and NURBS curves. Many sophisticate architecture studios have these tools in their design repertoire as well. Further contemporary techniques like sub division surfaces typically also start at a geometric primitive but can quickly diverge.

14 The author does not deny that most pavilions could have started as a geometric primitive when first sketched by the architects. This is even very likely given the set of contemporary digital design tools. It appears that a retrospective perception of a person, not involved in the design process, seems to emphasise on additional properties.

15 See also the discussion about symmetry and axis in 8.4.

ations are unfeasible in architecture space because the buildings must structurally resist gravity and still be economically reasonable.

- Architecture space is not completely independent of scale. The human body is the reference object. Though this aspect is not so important because most of the analysed World Exposition pavilions are within a similar size range.
- Many of the pavilions seem to consist of only one major distinct building part, but this one distinct building part had significant identity driving properties.

The absence of a geometry centric system was unexpected. This observation must be taken with a bit of caution. Of course this might very well be rooted in the selected buildings. World Exposition pavilions are to a certain degree special.[16] But maybe the reason is: That contemporary architecture, or at least World Exposition pavilions are often complex in their geometry.

With the introduction of a *Building Shape Periphrase* (see chapters 6.5 and 7) it was possible to react to these challenges:

Properties of Building Shape Periphrases include:

- *Circumlocution* and paraphrase of *qualitative* properties and features instead of a *quantitative* description of transformation steps of a stereotypical geometry.
- Integration of a novel classification set based on *tilt*. It connects geometry, gravitation and human vision.
- Advancement and fine tuning of known classifications sets like Proportion, Spacing, Feature and Curvature.

Based on the new influences the hypothesis was adapted:

Hypothesis: It is possible to overcome shortcomings in building shape classification of traditional architecture databases, when we adapt patterns from Cognitive sciences like Generative Linguistics and Vision. Cognitive concepts like vocabulary, implicit statements, lexicon, syntactic trees, and recursive rules are candidates that can bring structure to architecture meta data. Such a system should be better performing then a simple tagging with keywords.

The derived sub-hypothesis focus on one of the above mentioned concepts:

- Concept 1 – Domain specific vocabulary
- Concept 2 – Implicit statements
- Concept 3 – Lexicon and synonyms

16 see chapters 6.3.1 and 6.1.

- Concept 4 – Syntactic trees and recursive rules (for composition of building parts)

To give the “Domain specific vocabulary” some additional foundation, insights from Visual Perception research have been incorporated in an interdisciplinary way. This was especially beneficial for the idea of a *Building Shape Periphrase* as it strongly relies on small enclosed vocabulary sets.

Part II

5. Interdisciplinary Approach

A question arises if other disciplines have created tools and techniques to manage complexity in their own domains and could architecture benefit from these tools and techniques? After we look into other domains, we will return to existing architecture classifications and review them with help of the newly gathered insights.

Researchers in cognitive sciences are trying to investigate the human mind and are therefore confronted with one of the most complex system known: the human brain. The research domain of *cognitive linguistics* becomes of interest because it works with languages constructed from words. The earlier mentioned *multiple keywords* are related and looking into pattern how to group words more efficient can be a valid path. Surprisingly "Generative Theory of Tonal Music" also plays a positive role.

The cognitive science domain of *perception and vision* deals with information processing starting from light rays hitting the retina, via object recognition, up to interaction with other parts of the brain. *Shape recognition* is one of the major topics that Vision researchers are trying to explain. Shape recognition and shape classification are related topics so it makes sense to investigate it.

We will concentrate on perception rather then construction of shape. Therefore one omission in this thesis is an interdisciplinary look into architectural geometry. Please see "Architectural Geometry" (Pottmann and Bentley, 2007) for an overview. Though we will look into precedence of *classification by shape* in architecture in chapter 5.4.

Readers of this thesis are most likely closer to Architecture and Civil Engineering disciplines then to Cognitive Science disciplines of Linguistics and Vision. Most of Chapter 5 is also intended to give these readers a convenient first look.

Disclaimer: We will find quite extensive quotes in this chapter, instead of paraphrasing by the author. These are often parts where the original authors summarised or reviewed important positions of their peers, and their choice of words is surely better then the one of an external observer. There is no claim by the author to have worked out any novel academic insight in Linguistics or Vision. In chapters 5.1, 5.2, 5.3, and to some extend in chapter 5.4, we will see light grey boxes marked as "[BSC]" which try to connect the other disciplines and approaches back into the context of Building Shape Classification.

5.1. Linguistics

For Linguistics we will look at contributions from two researchers and their associated co-authors. Please be aware that they are part of bigger movements and that there are thousands of active researchers in linguistics. The selection of these two is mainly due to the interdisciplinary nature of this thesis:

- *Noam Chomsky* – helped triggering the "cognitive revolution" in Linguistics and introduced three seminal works within his field. He represent the mainstream view in his domain. He is one of the most cited scientists of all time. He is also known as a political activist.
- *Ray Jackendoff* – Is in some parts in opposition to the mainstream view in Linguistics and offers an alternative approach called *Parallel Architecture*. He is of interest for this thesis because he himself has a strong interest in interdisciplinary work and his proposed system is open for extension.

Unfortunately a full introduction into Linguistics is out of scope. Please see "Chomskyan linguistics and its competitors" (Hacken, 2007) for an overview of current research programs in Linguistics including – but not limited to – Chomsky and Jackendoff. The following chapters do not try to introduce Chomsky's and Jackendoff's work in its full language science implication. By contrast, we will cherry pick concepts that can be useful for the task at hand: Building Shape Classification (BSC). Small paragraphs in between the linguistic content with an architecture focus will try to show the potential connection and lessons to learn. To make it easer for the reader these paragraphs are marked by a prefix: "[BSC]".

Linguistics is a very specialised science and uses a lot of terms in a very precise manner meant for peers. The following are some encyclopedia definition together with informal notes of a few terms which we will encounter in this chapter. Readers with a different background can follow easier when they are aware of these terms. The "The MIT Encyclopedia of the Cognitive Sciences" explains the high level research fields as:

> "The logico-philosophical tradition divides semiotics (the study of signs, applicable to both natural and constructed languages) into syntax, semantics, and pragmatics" (Wilson and Keil, 1999, p. 739)

It follows to describe each field in one sentence[17]:

- "*syntax* concerns properties of expressions, such as well-formedness;" (Wilson and Keil, 1999, p. 739). A more verbose definition is: "The term syntax is also used to refer to the 'structure' of sentences in a particular language. One aspect of the syn-

17 Bullet points added for clarity.

tactic structure of sentences is the division of a sentence into phrases, and those phrases into further phrases, and so forth." (Wilson and Keil, 1999, p. 818). Typical parts of speech like noun, verb, etc. appear in these phrases. We can see from this definition that phrases use *recursion*.[18]

- "*semantics* concerns relations between expressions and what they are 'about' (typically 'the world' or some model), such as reference;" (Wilson and Keil, 1999, p. 739). *Meaning* is also a term which is closely associated with *semantics*.

- "*pragmatics* concerns relations between expressions and their uses in context". (Wilson and Keil, 1999, p. 739)[19] The context can be of various kind. For instance: pointing at something, knowing something from the sentence before, common ground, being at a certain place. We can think of a context for a building in terms like: location, climate zone, budget, application, etc.

We will encounter *syntax* early with Chomsky and read more about *semantics* and *pragmatics* in the chapter about Jackendoff. We will define three more terms in this domain glossary:

- "*Phonology* addresses the question of how the words, phrases, and sentences of a language are transmitted from speaker to hearer through the medium of speech. [...] The phonological system of a given language is the part of its grammar" (Wilson and Keil, 1999, p. 639). We will see that *phonology* tries to analyse the same sentences that *syntax* does, but uses different notations and tools.

- *Grammar* – The "Encyclopedia of Language and Linguistics" documents several usages of the term. We will follow the definition of "grammar comprises syntax (the study of sentence structure) and morphology (the study of the structure of words)". (Brown, 2006, vol. 5, p. 113) We can observe that grammar is about linguistic data structure. For this thesis it is of interest to see that the term comprises two different items: sentences and words. We will later introduces *two* distinct building shape data structures and connects them with something that has a similar role like grammar in linguistics. The definition of *generative grammar* (next glossary item) starts with a further accessible definition of *grammar*: "The term 'grammar' itself can be loosely defined as the set of rules that accurately describe the combination of elements in a language. [...]"(Brown, 2006, vol. 5, p. 767)

- *Generative Grammar* – "[...] A properly 'generative' grammar is, roughly speaking, a grammar whose rules generate (i.e., produce) all and only the correct combinations of elements in a language. This definition corresponds to the use of generative grammar as a common noun. However, the term 'generative grammar' gradually

18 For *Recursion* see Glossary chapter 2 and chapter 8.1.

19 See also (Wilson and Keil, 1999, p. 661) for a more formal definition of the term *Pragmatics*.

received a much broader meaning as a proper noun, referring to the specific research program that is associated with the mentalist approach to language launched and developed by Noam Chomsky." (Brown, 2006, vol. 5, p. 767). The encyclopedia article later continues: "The narrower, common noun meaning of the term 'generative grammar' originates in mathematical recursive function theory and is also used in computer science." (Brown, 2006, vol. 5, p. 767) The use of *recursion*[20] makes generative grammar accessible to people that have experience in *software development*[21]. This is important to this thesis because it is the intent of this research to provide a working software implementation of the major parts of the theory.

5.1.1. Chomsky

Seminal works like "Syntactic Structures" (Chomsky, 1957) introduced a new cognitive research programs around *Generative Grammar* which is now the mainstream in language science. It replaced behaviourism as the dominant research methodology. Among many innovation one distinguished idea is that humans, and especially children, have an *innate* capacity for language. This internal language (I-Language) competence allows children to acquire language at a rapid pace. This is different to the behaviourism point of view where the human mind is a blank slate and all knowledge about a language comes from external sources (E-Language).

[BSC] For architecture we might speculate that the definition of a *high rise* or a *train station* is not innate, but maybe the idea of a shelter to protect from environment forces already made it into our genes. Also there might be an innate competence to walk through three dimensional environments. By walking through and around these buildings we deal with building shape.

[BSC] We can see that Alexander is also following the thought of an I-Language paraphrasing it for his architecture design process. In the following quote "language" refers to the architecture pattern language that he introduces: "But is is not yet a fully living language" (p. 336) [...] "A language is a living language only when each person in society, or in the town, has his own version of this language." (p. 337) [...] "A living language must constantly be re-created in each person's mind" (Alexander, 1979, p. 338) He continues to describe the "innate capacity" that enables the learning process of a child that acquire English in the same way that cognitive linguists would and then connects it back to his architecture pattern language.

---

20 For *Recursion* see Glossary chapter 2 and chapter 8.1.

21 "Software development" (also known as programming) is here understood as the applied use of computer science – especially mainstream programming languages – as a tool in an other domain. The author of this thesis works as software developer.

Chomsky provides a solution to the problem how humans can understand or produce an infinite amount of sentences which they have never heard or spoken before. The human language competence is focused around *generation* of syntax and grammar; hence the name *Generative Grammar*. There is only a finite set of elements and rules necessary to achieve this. Chomsky himself cites – a now famous – sentence of Humboldt: “makes infinite use of finite means”[22]

[BSC] This capability, to understand never heard before sentences is of interest to research of building shape. Many prominent architecture buildings have never seen before building shapes. Still observers have in nearly all cases no problem to identify them as buildings and expect them to follow certain rules. Therefore we might argue in a typical cognitive style: architects do not only have a capability to *create* never seen before building shapes but the users have the capability to *parse* them.

[BSC] The famous cognitive linguistics catchphrase “makes infinite use of finite means” can be used as an indicator that other researchers are aware of the cognitive revolution. We can trace it in Alexander’s work in a paraphrased adapted version: "More important still, because they [the diagrams] are abstract and independent, you can use them to create not just one design, but an infinite variety of designs, all of them free combinations of the same set of patterns."(Alexander, 1964, preface of 1971 edition) Alexander dedicates multiple chapters in “A timeless way of building” (1979) to discuss *his language* and at multiple places points back to the similarity of spoken/written languages. Alexander’s “language is created by the network of connections among individual patterns". (Alexander, 1979, p. 305). This focus on just connections makes Alexander’s pattern language less analytical then Chomsky’s full linguistic framework. Still we can observe a researcher from one domain – architecture – being inspired in an interdisciplinary fashion by a different domain – linguistics.

In the last 60 years the mainstream generative grammar frameworks have been revised and variations of the framework compete in academic discourse. Chomsky provided three major contributions:

- 1957 - Generative Grammar (Standard Theory)
- 1981 - Government Binding Theory
- 1990 - Minimalist Program

We can observe that the three concepts *phonology*, *syntax* and *semantics* are not treated equally. In the mainstream view *syntax* is taking the central role and the combinatorial

22 Noam Chomsky (1965), *Aspects of the Theory of Syntax*, MIT Press, Cambridge, MA.

structures originate from it. Only syntax has the capacity to *generate* structures. The combinatorial structures of *phonology* and *semantics* derive from syntax. Arriving at the Minimalist Program there is even more focus on *syntax* then before. “A consequence of this assumption is that syntax is forced to be at least as combinatorially complex as semantics” (Jackendoff, 2017, p. 6).

One central thought introduced by *generative linguists* (Chomsky, 1957) is the idea that it might be possible to investigate *syntax* of a sentence – to a significant extend – independently from its *meaning/semantics*. This can be followed by reading the sentence “Colorless green ideas sleep furiously” which is meaningless but perceived as grammatically correct.

[BSC] The idea that it is possible to investigate syntax separated from meaning might be interesting for building shape as well. We have already seen in the definition of the term *building shape* that we distinguish between *shape* and *form*. When we treat *shape* similar to *syntax* then *form* could be closer to the linguistic idea of *meaning*. Though we will later see that Jackendoff would draw the lines differently.

The focused view just on syntax allowed Chomsky to develop visual tools like the tree diagrams in Figure 7. These diagrams follow the rules of a *binary tree* which is a well known data structure in computer science and logic. Therefore Chomsky introduced a new visual notation in his discipline which enabled linguist to communicate and reason about syntax in a novel way. It also helped to unlock language to be accessible for certain kinds of computational processing.

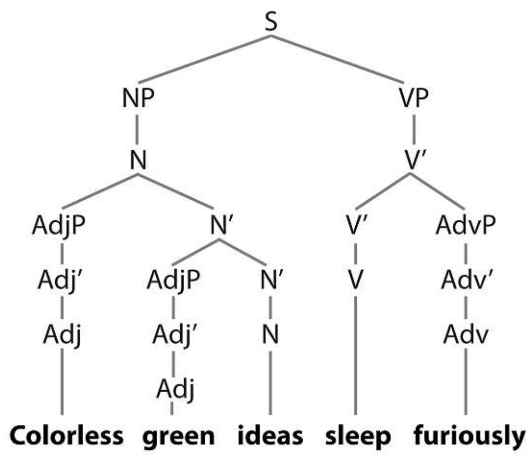


Figure 7: A sentence with valid syntax but no meaning and its binary syntax tree.
Diagram based on Waitingxu

The binary trees used in mainstream generative linguistics allow tree nodes to have either one or two children. The use of hierarchical data structures in cognitive science is common because there is consensus that the human brain is very efficient in computations of such data. One trick why humans and computers are efficient is the fact that these structures can be *recursive*. The pattern is repeated over and over again at different levels. The computational effort at one single tree node of a binary tree is quite low. Still recursion allows that the whole binary tree can be quite complex.

5.1.2. Jackendoff

Interdisciplinary

The linguistic work of Ray Jackendoff and colleagues is identified as one of the competing programs (Hacken, 2007) to the mainstream view.

Ray Jackendoff is an established linguist[23] who is contributing to the field since the sixties. He is of interest to us because he himself is interested in interdisciplinary work. In this chapter we will focus on his linguistic work, but he has also teamed up with music composer Fred Lerdahl to analyse music (see chapter 5.2). For an outside observer his work is in many ways in *a Cognitive Tradition* started by Chomsky, though Jackendoff diverges at some points within his field. Unlike Chomsky he wants to investigate the building blocks of linguistics like phonology, syntax, semantics and pragmatics more interrelated and less in a silo fashion. He goes even further and sees potential that similar patterns are repeating all over the human brain.

> "My working hypothesis is that memory, processing, attention, and learning are pretty much the same all over the brain. And I believe that structural features like grouping, sequencing — and even recursion — are common to many different kinds of mental representations (Jackendoff, 1987a, 2002, 2011; Lerdahl & Jackendoff, 1983; Pinker & Jackendoff, 2005). But that can't be the end of the story: One must also specify what makes vision different from language, and language different from music (Jackendoff, 2009; Patel, 2008), and music different from actions like washing dishes, and washing dishes different from morality (Jackendoff, 2007a). My working hypothesis here is that these differences are a consequence of the character of the mental structures appropriate to each;" (Jackendoff, 2017, p. 4)

As a logical consequence his own linguistic framework, titled *Parallel Architecture,* has the flexibility to link up to other cognitive domains like Vision. Jackendoff sees his approach similar to the one by Vision researcher Marr, whom we will cover later in chapter 5.3.1.

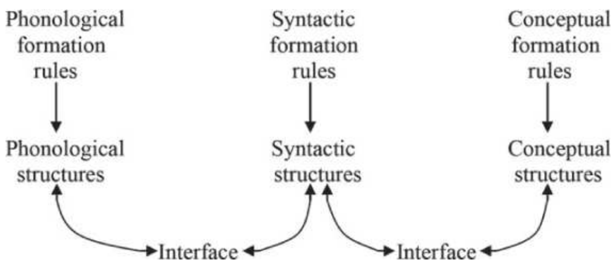


Figure 8: Figure visualising Jackendoff's definition of the *Parallel Architecture (Jackendoff, 2017) (Figure 1)*

23 In 2014 he received the Rumelhart-Price, one of the major awards in the field of cognitive science.

Parallel Architecture

Jackendoff acknowledges that the standard theories and programs of the mainstream view have contributed to many valuable insights but points out that they do not fit very well when it comes to *language processing* and l*anguage acquisition*. This is why more and more researchers interested in experimental work are giving up on the mainstream ideas (Jackendoff, 2017, p. 4). One of his motivations is to offer an alternative theory for these groups[24].

Jackendoff's definition of the *Parallel Architecture* is the following:

> "Mainstream linguistics has for the most part ignored the combinatorial independence of phonology and semantics from syntax. But if we take it seriously, we arrive at a parallel architecture, in which phonology, syntax, and semantics are on an equal footing [Figure 8] Each of the structures has its own combinatorial principles, but in addition they are linked by interface principles, which are what enable language to map between sound and meaning. A phrase or sentence is then a triple of well-formed phonological, syntactic, and conceptual structures, plus links among them established by the interface components." (Jackendoff, 2017, p. 6)

Beside of the more equal roles of *phonology*, *syntax* and *semantics* Jackendoff emphasises *interface* principles that are an integrated part. He also stresses that it is not a strict sequence of operation but rather simultaneous "opportunistically 'clipping'". He hopes that by having three smart connected data structures available at once, it should be easier for language processing of humans and computers to not get stuck in ambiguities.

The *semantic* part gains smartness by being allowed to take over ideas which in the mainstream view are only available in the *syntax* part. Even grammar rules are not exclusive to syntax any more. Jackendoff proposes that they can also exist in the *lexicon*. By having three structures available Jackendoff can also experiment what happens when we turn one of them off. He finds out that for some sentences it is possible to have the syntax structure turned off and the remaining parts can still explain certain tough language problems. This is something that is not possible in the mainstream view, where everything depends on syntax.

Mainstream researchers criticise the Parallel Architecture on two grounds:

- By having three generative engines plus these interfaces the system is more complex than the Minimal Program which requires only a single engine; the one for

24 Jackendoff's theory is not the only one that tries to address these shortcomings. He points out that other alternatives like Head-Driven Phrase Structure Grammar (HPSG) and Construction Grammar also see a problem in the emphasis on syntax in the mainstream and also provide alternatives (Jackendoff, 2017, p. 5). Jackendoff criticises that nowadays typical graduate students are learning the topics of phonology, syntax and semantics in isolation with hardly any connection between them.

syntax. The reply (Jackendoff, 2010, p. 4) to this is, that the Minimal Program does not describe a combinatorial structure for *phonology* and *semantics* or an alternative how they might work, so it is no surprise that at that moment it only has one generative engine.

- The second argument of critics is that the Parallel Architecture contains redundancies and is therefore not the most efficient system possible, while the Minimal Program tries to avoid redundancies at all cost and assumes that the perfect efficient system must be the one present in the human brain. The reply (Culicover and Jackendoff, 2005, p. 543) to this is, that the quest for the perfect redundancy free system is to limiting and that redundancies are present in other cognitives sciences like Vision (see chapter 5.3). For instance in Vision there is more then one way to understand visual depth with different depth cues like shade, texture, shadow, etc.

[BSC] What can we learn for building shape classification from the overall layout of Jackendoff's Parallel Architecture? It might be valid to have more then one major component instead of trying to fit everything into one perfect structure. We will see this happening with the pair Building Shape Periphrase and Building Shape Syntax Tree. Also, it is a good thing to eliminate redundancies but one should not be to dogmatic about it. On a high level scale we can see redundancies in architecture analysis as well. For instance the Structural Design Aid (SDA) database has two applications for shapes (see chapter 5.4.3). On the one hand *building shape* similar to the topic of this thesis, on the other hand the *shape of the load bearing physical structure*. For the analysis of some buildings they might overlap and look redundant, but for other buildings they might diverge and help to understand them better.

Beside of the overarching ideas of a *Parallel Architecture*, Jackendoff's contribution can be broken up into three subcomponents, each one supported by many years of research:

- Conceptual Semantics
- Lexicon with a more important role
- Simpler Syntax

We will add two further points that are of interest to building shape and look into all five of them one by one:

- Information Structure in language
- The role of Pragmatics

First subcomponent: Conceptual Semantics

Jackendoff places semantics on the right hand side of Figure 10 and they are more internal then phonology and syntax. Jackendoff positions his *Conceptual Semantics* in between the strict logic based *formal semantics* and the much "softer" *cognitive grammar*. Jackendoff sees his approach as I-Semantics (internal(-lised) semantics) rather then E-Semantics (external(-ised) semantics). So he is in a certain Chomsky tradition here.

As mentioned above. Semantics gets its own combinatorial structures at eye level with syntax. Jackendoff assumes that this structure is a recursive n-ary tree structure and some of the same performance and simplicity benefits are present.[25] . *Conceptual Semantic* can therefore encode *meaning* and make it also decomposable. This is done in a similar fashion like syntax: there is a finite stock of primitives and principles which can handle an infinite grasping of meaning. But the rules and principles are not *well-formed*, so they are not so strict and logic based. There is no strict enumeration of inclusion and exclusion like there is in Formal Logic. The system is rather one of "fuzzy borderlines and family resemblance properties" (Jackendoff, 2010, p. 10)

[BSC] This fuzziness and family resemblance is also present in building shapes. At a small scale when we talk about angles in shapes they have an overlap with the information on edges. For instance a continues sequence of very obtuse angles is similar to a very smooth shape with smooth edges. Still we should not try to drop *obtuse angle* from the angle classification set or the *smooth edge* from the edge classification set, as we can benefit from them within their peer items.

Phonology: æl_1 $\text{layk}_2\text{-s}_3$ tuw_4 swim_5

Syntax: $[_S\,[_{NP}\,N]_1\,[_{VP}\,[_V\,V_2{+}[\text{pres}{+}3\text{sg}]_3]\,[_{VP}\,\text{to}_4\,V_5]]]$

Conceptual structure:

$$[_{State}\,\text{PRES}_3\,[_{State}\,\text{LIKE}_2\,([_{Person}\,\text{AL}]_1{}^{\alpha},\,[_{Event}\,\text{SWIM}_5\,([\alpha])])]]$$

Figure 9: The simple sentence "Al likes to swim" from (Jackendoff, 2010) page 26; expression 25. The three different lines represent the same sentence but each in its specialized notation. Phonology is a linear structure, but Syntax and Conceptual Structure used brackets and parenthesis to transport further information. These brackets and parenthesis are a different one dimensional representation of a tree structure. Please note that the brackets/hierarchies in Synatx and Conceptual Structure are at different places. Jackendoff tries to show that it is problematic to have one unifying structure even for a simple sentence.

25 The formation rules in the semantic/conceptual structure follow their own set of patterns with function-argument, modifer-head relations, and binding. The details are to specific for this interdisciplinary overview.

Second subcomponent: Smarter Lexicon "Kick the bucket"

Most language theories have a component in it called the *lexicon*[26]. It is the place in the human mind of long term memory for words and morphemes. In the mainstream theories the role of a lexicon and lexicon items is a rather passive lookup operation. In the Parallel Architecture the lexicon has a more prominent and active role (see Figure 10). We mentioned earlier that the *interfaces* between phonology, syntax and semantics are an integrated part in Jackendoff's approach. The opportunistic "clipping" together at the interfaces actually happens in the form of lexical items.

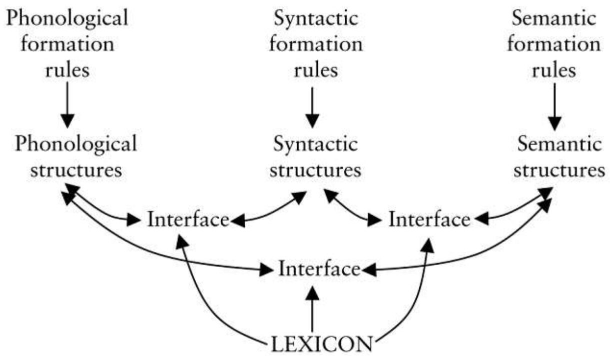


Figure 10: The position where the lexicon is plugging into Jackendoffs parallel architecture. The lexicon interacts with all interfaces. From (Culicover and Jackendoff, 2005); page 37; Figure 1

> "we can think of lexical items as being inserted simultaneously into the three structures and establishing a connection between them. [...], as interface constraints, they play an active role in the construction of sentences." (Culicover and Jackendoff, 2005, p. 19)

Culicover and Jackendoff allow not only to store words in the lexicon but also idioms and clichés like "*kick the bucket*" as an idiom of *die*. Culicover and Jackendoff point out that "kick the bucket" itself has a simple syntax structure. Their version of the lexicon is able to store this basic hierarchical information as well. They follow the thought even further: When they can store hierarchical structures of idioms, then they might also store the more generic structure which is actually a phrase structure rule.

We can look at "kick the bucket" in the four structures

> Written: Kick the bucket
>
> Phonology: /kIk#ðə#bʌkət/
>
> Syntax: [VP V [NP Det N]]
>
> Semantics: DIE (X)
>
> (Jackendoff, 2017, p. 9)

26 A dedicated publication on the lexicon is "The texture of the lexicon: Relational morphology and the parallel architecture" Jackendoff, R. and Audring, J. (2020). Oxford: Oxford University Press

[BSC] What can we learn for building shape classification? Any storage of a vocabulary does not need to be a passive lookup system, but can do smarter things as well. The vocabulary items that we are interested in a terms like convex, concave, high point, faceted, vertical, etc.

Third subcomponent: Simpler Syntax

With the introduction of the ideas above:

- (1) An overarching layout of equal weighted phonology, syntax and semantics with their own combinatorial structures;
- (2) semantics with its own generative capacity takes care of *meaning;*
- (3) a smarter lexicon that works as the interface;

Culicover and Jackendoff are now in a position to redefine the role of syntax:

> "Syntax functions in the grammar not as the fundamental generative mechanism, but rather as an intermediate stage in the mapping between meaning and sound (in either direction) [...] But syntax need not encode any more of semantic structure than is necessary to map between phonology and meaning" (Jackendoff, 2010, p. 20)

This makes their version of syntax much simpler then the mainstream syntax, hence the name *Simpler Syntax*. This is in contrast to the mainstream view, where syntax is "under constant pressure for greater articulation and complexity" (Jackendoff, 2010, p. 4)

Simpler Syntax still has syntactic combinatorial structure and this is intended[27]. Though Culicover and Jackendoff are not so strict about pure binary tree hierarchies and allow n-ary trees[28]. This allows their trees to avoid moving parts. The movement of nodes makes mainstream syntax complicated. This solution is partly enabled by the layout of the Parallel Architecture. The audio signal from phonology is always linear, and this information can be accessed simultaneously in the Parallel Architecture. The phonology structure is delivering the linear sequence for free.

[BSC] While the mainstream view and alternatives like Culivcover and Jackendoff argue about the role of syntax, they agree that hierarchical trees are a useful tool for data processing. The mainstream view sticks strictly to binary tree while Culicover and Jackendoff can use n-ary trees because they have phonology structure to help

27 Though the role of syntax is reduced to word order, case marking, agreement, handling of long-distance dependencies and the existence of special constructions. This is beyond the scope of our interdisciplinary view.

28 A *n-ary* tree is not limited to be a binary tree with only two child nodes, but can have more child notes. For instance three, four or five. In Simpler Syntax there are mostly two or three children per node.

them. We will see the use of binary trees later in this thesis and they will be binary only. We will use the binary tree as the primary place where we define a sequence of ranked importance. So we will be closer to the mainstream view, because we do not have a helper structure like Culicover and Jackendoff have.

In the mainstream view as well as in Jackendoff's approach *recursion* is an important pattern. Navigating through binary or n-ary hierarchies with always the same simple computational rules on each local node is very efficient. The mainstream view assumes that recursion might be exclusive to human language and distinguishes us from animals. Jackendoff argues that recursion also pops up in Vision (and music and task planing). We can assume that due to the evolutionary ties of our biological eyes the same cognition pattern are present in animals (Jackendoff and Pinker, 2005, p. 211) . Jackendoff also points out that some recursion in Vision can be connected to Gestalt principals (2005, p. 217).

[BSC] For building shapes, we might benefit from an approach that is based on binary or n-ary hierarchies with recursion. When we follow Jackendoff we can assume that recursion can pop up in even more places. Recursion is well understood in computer science and part of many programming languages.

Orthogonal dimension of information structure

Additional to the three subcomponents: conceptual semantics, lexicon and simpler syntax Jackendoff is also investigating his linguistic theory in relation to linguistic *Information Structure*. He sees this concept as an orthogonal aspect.

> "Information structure is concerned with the role of the sentence in the speaker-hearer interaction—the means by which the speaker intends the sentence to inform the hearer, in the context of previous discourse. The simplest illustrations of information structure phenomena are question-answer pairs" (Jackendoff, 2002, p. 408)

[BSC] For building shape classification in this thesis we might argue that the "speakers with the intent" are the architects that designed a building. We have two kinds of "hearer":

The person that creates the data files with building shape classification proposed in this thesis. This person follows the pattern: "This is the building shape. What is the corresponding building shape classification? It is ..."

The people that participated in the empirical data gathering. They had a pattern: "Given this building with the building shape on the right, what are the most similar building shapes from the buildings on the left? It is this one, then that one, then ..."

Terms from Information Structure like *focus*, *topic*, *old/new information*, *common ground* and *joint believe* differ for the two above hearer groups. We will not use them in building shape classification but it is a valuable insight to know that there might be orthogonal information structures and not everything need to fit into one box.

Pragmatics

Pragmatics is the linguistic term of the actual use of language in a given context[29]. It often helps to establish a common ground[30] between communication partners that reaches beyond one sentence with one meaning. Theses can be so diverse things like connecting a spoken sentence to:

- the sentences before the spoken one
- irony and metaphor
- pointing at something
- being at a certain physical location, that serves as a reference point
- the cultural context

The mainstream view is not certain where to put pragmatics. It tends to put it *after* semantics in a chain of processing. Sometimes there is a distinction between semantics as a kind of "dictionary" and pragmatics as an "encyclopedia".

Jackendoff admits that these kind of distinctions are tempting and seem to be based on sound intuitions. He still rejects a strong separation of the two concept: "There is no formal distinction of level between semantics and pragmatics" (Jackendoff, 2010, p. 8). It must be stated that Jackendoff does not question the value of pragmatics but only the place where the mainstream is positioning it. He believes that pragmatics plays an important role:

> Moreover, speakers may be tolerant of ''imperfections'' such as ambiguity, because they have pragmatics to help guide interpretation. A tolerance for ambiguity in turn may make it

29 See also (Wilson and Keil, 1999, p. 661) for a more formal definition of the term *Pragmatics*.

30 A linguistic introduction to "common ground" and related terms like "mutual knowledge" and "assumed familiarity" can be found in chapter 1 and 2 of Allan, Keith. (2012). What is Common Ground?. Perspectives on linguistic pragmatics. 2. 10.1007/978-3-319-01014-4_11.
The term "joint believe" is also a synonym.

> possible to communicate in less time and with less effort to achieve precision. (Culicover and Jackendoff, 2005, p. 542)

[BSC] The positive role of pragmatics that linguists permit it to play is significant for building shape classification. If one reads at length into any linguistic framework the subject matter becomes very abstract pretty fast. And it is okay, because language allows such abstract analysis and it is closely related to the human mind and even more abstract things like meaning and moral. The reference of pragmatics helps to realize that the task at hand – building shape classification – is not *that abstract* but related to, at least to some degree, to the physical world. We look at building shapes in the real world and they have *context* associated to them. On the one hand this context are environmental effects like gravity on the other hand they are cultural or economical norms like upright walls. There is also the context that we only look at World Exposition pavilions that follow certain patterns[31].

Following Jackendoff it is okay to get help from the context. It will help tolerating ambiguity and work with less effort. We will see the role of context reappear when we look into Vision.

Towards Music and Vision

We pointed out in the first paragraph about Jackendoff, that he is of interest because he himself is interested in interdisciplinary work. One remarkable thing is that Jackendoff is not only pointing towards potential cross discipline work, but he actually conducts this kind of research and publishes it.

There is a classic linguistic question: "How do we talk about the things that we see?". This lets some linguists look into Vision and perception. Jackendoff himself has published some research papers about this intersection. When it comes to Vision he is influenced by the approach of David Marr or at least the *Marr tradition*. We will look into Marr in chapter 5.3.1. Marr proposed a system with three conceptual components with interfaces in between them, so there is no surprise that Jackendoff sees similarities there with his Parallel Architecture. As his theory is open for extension, it could create "yet another interface" between the semantic subcomponent and a visual system[32] .

31 Another example: The participants in the empirical data gathering have looked at the same set of buildings for 90 minutes. Within this time, they look at some repeating screens with the context of their prior experience.

32 And it is not just plugging into another system. Jackendoff finds strong motivations for his linguistic work

> "Finally the connection between language and vision by necessity cannot be implemented by a derivation from syntax structure. On form grounds, the unit of vision is far to distant from those of syntax. But more importantly visual cognition has existed in the animal kingdom far longer then language, so on evolutionary grounds a derivation from syntactic structures is worse than plausible. As a consequence it became necessary to express the conceptual-structure-to-3D model connection in terms of

In another endeavour Jackendoff looked into a possible data structure for "task planing" which can be useful to understand humans but also has its need in robotics (Jackendoff, 2007, p. 111). As part of it he tries to find out if the techniques from linguistics can be applied to this field as well. His two examples are the tasks: "shaking hands" and "making coffee". It is surprising how complex the action can become when one drills down, as shown in Figure 11. He manages to stay within his proposed system and adjusts a hierarchical data structure to fit the need.[33]

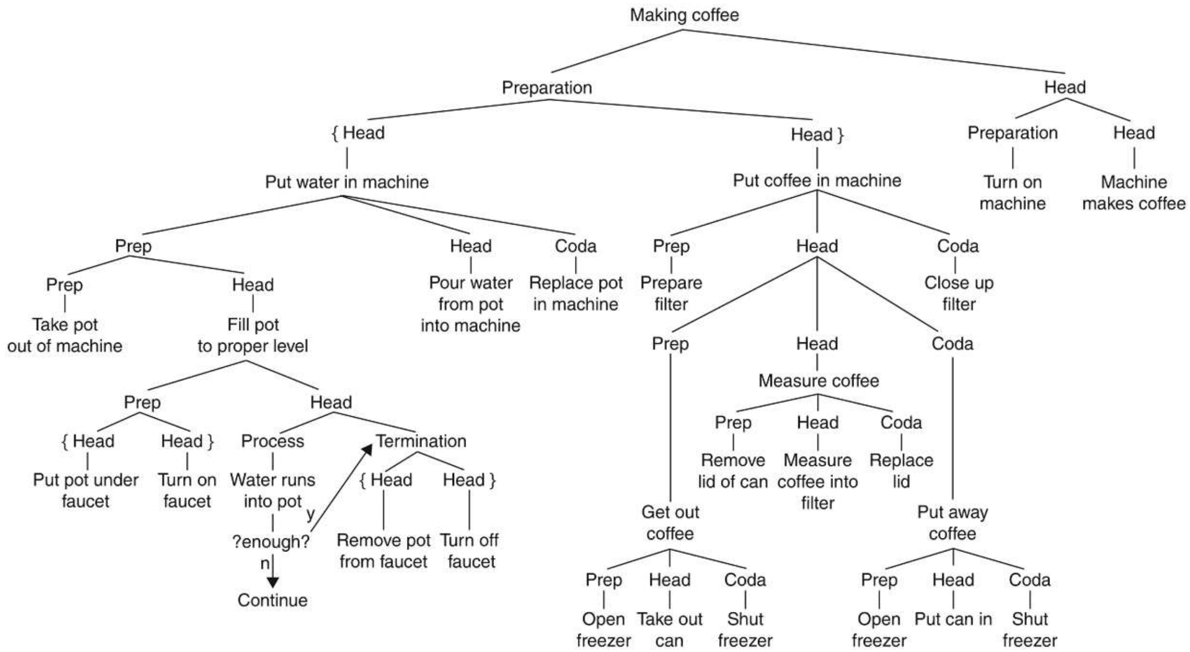


Figure 11: The task of "Making coffee" broken up into a hierarchy of smaller tasks. From (Jackendoff, 2009); Figure 2

[BSC] In the introduction of this thesis we decided to not concentrate on a *physical shape* definition but rather a *perceptual shape* definition. Perceptual shape is closer to cognitive science. Interdisciplinary works like the "making coffee" by Jackendoff are encouraging as they cover yet another cognitive domain and show that the techniques might work in more cognitive fields. We will omit further details about *complex task planing* but instead move on to another interdisciplinary project of Jackendoff: The work on "Generative Theory of Tonal Music" together with composer Fred Lerdahl.

> interface rules. This treatment was an important motivation towards the Parallel Architecture within language."(Jackendoff, 2010, p. 86)

Jackendoff emphasised in his 2010 book "Meaning and Lexicon" the importance of these influences and reprinted two of his original papers about Vision.

33 There are nodes with a *head*, *preparation* and an optional *coda*. Coda is an action that return the branch it its previous state. There are also unordered heads present, because sometimes it does not matter in which order we do things. There are simultaneous heads present, as we can do two things at once, etc.

5.2. Generative Theory of Tonal Music

From an outside observer perspective, linguistic syntax and Jackendoff's parallel architecture are fascinating. Though transferring knowledge and techniques from a highly dynamic discipline like generative linguistics to a different discipline is a challenging task.

Due to an interdisciplinary project initialized by Leonard Bernstein, Jackendoff teamed up with composer Fred Lerdahl. Together they introduced “Generative Theory of Tonal Music” (Lerdahl and Jackendoff, 1983). They discovered early that a direct transfer of linguistic syntax was not feasible for music. They managed to transfer linguistic thinking and techniques into music theory without trying to force music into a ridge linguistic-like syntax framework.

They points out that the ability to achieve musical competence is not the same as with language. While we all learn language, we are not required to learn music. Some people are gifted and other are tone-deaf. Most are somewhere in between. They argue that musical capacity and language capacity must have different properties but it is still valid to try to look into similarities. (Lerdahl and Jackendoff, 1983, p. 2)

One of the major differences is: language conveys *propositional* thought, while music enhances *affect* or *emotion*. Poetry is a hybrid form where both properties are present (Jackendoff, 2009, p. 193).

[BSC] Building shape classification can benefit from this assumption. As discussed in the introduction *building shape* can be analysed to some extend without *building form*. Though similar to poetry, a building as a whole has both properties. During the classification and the empirical data gathering the participants were instructed to ignore all other aspects and try to concentrate only on the shape. Though they looked at photographs of whole buildings. There might always have been some influence from the *emotional* part. But we can analyse poetry on a syntax level as well as on an emotional level, so the same should be acceptable for building shape.

Preference Rules

Lerdahl and Jackendoff state that there is an additional concept in music theory which is not present in language theory: They claim that an “experienced listener is more likely to attribute some structures to the music then others” and call these *preference rules*. These preference rules play an important role in most parts of their theory For instance if an experienced listener hears variation of a piece of music and the task is to point out which variation is the closest to a reference then it is a decision of “preferred” interpretation. Terms like “more likely” and “preferred” are actually soft, and are quite apart from engineering theories that look for determinism and precision. Still Lerdahl and Jackendoff show that variations or reductions of music pieces that have been deliberately manipulated to be slightly off, are less preferred by an experienced listener then the reduction that follow the rules that they introduce in their theory[34].

[BSC] For building shape classification this promotion of preferential rules is quite helpful at the classification level: The decision if a building shape falls into one bucket or the neighbouring bucket is often not hard science but rather the preference of the “experienced person doing the classification”. This is also something that Otto and his team are pointing out. Though we will see that there are technical helpers that avoid that these decision are to black or white.

Reduction

Lerdahl and Jackendoff state that *reduction* is an analytical tool in music theory:

> “An obvious observation about music is that some musical passages are heard as ornamented versions, or elaborations, of others. For instance, despite the surface differences in pitches and durations between examples 5.1a and 5.1b, [see Figure 12 in this paper], from the finale theme of Beethoven's Pastoral Symphony, the listener has no difficulty in recognizing 5.1 b as an elaboration of 5.1a.” (Lerdahl and Jackendoff, 1983, p. 106)

5.1

Figure 12: “Figure 5.1” from (Lerdahl and Jackendoff, 1983, p. 106)

As *Expansion* it also works in the other direction. *Reduction* becomes an important hypothesis in their theory:

> "Reduction Hypothesis: The listener attempts to organize all the pitch events of a piece into a single coherent structure, such that they are heard in a hierarchy of relative importance, This hypothesis is central to Schenkerian analysis and its derivatives" (Lerdahl and Jackendoff, 1983, p. 106)

34 There is also a similarity in linguistics: Not all sentences mean what they mean literally. Influences from Pragmatics can be present with things like irony, location context, and many more. See the section on Pragmatics in chapter 5.1.2.. “Many principles of pragmatics appear to have the nature of preference rules” (Lerdahl and Jackendoff, 1983, p. 310).

Prolongational Reduction

Besides of poetry Jackendoff emphasises that there is no one-to-one mapping between language structure and music structure. Neither, rhythm, pitch, words or syntax are present with the same principles in the other domain. The terms are sometimes reused but their function and principles are different. The concept which has the most connection is the *prolongational structure*, but even there its a transfer of techniques and not one of the same structure[35].

The term is quite abstract for readers not involved into music. An accessible definition might be:

> "Prolongational structure creates patterns of tensing and relaxing as the music moves away from stability and back towards a new point of stability. [...] these patterns of tensing and relaxation have a great deal to do with affect in music" (Jackendoff, 2009)

Lerdahl and Jackendoff introduce a binary tree structure like in Figure 13 which looks similar to linguist syntax trees but actually describes *prolongational reduction*. This binary trees are inspired by notation from linguistics and are also *headed.* At a tree node, one branch dominates the other, and it continues to rise to the top. The higher up the tree the more intense the reduction. A passage of music could be reduced from dozens of musical notes to just a handful and a test audience would still prefer these reduced version to be more similar to the original music piece than other reductions.

35 Quotation:

> "The closest musical counterpart to syntax is GTTM's prolongational structure, which was originally inspired by the recursive reductional hierarchy of Schenkerian theory." (Jackendoff, 2009) GTTM is abbreviation of the book title "Generative Theory of Tonal Music"

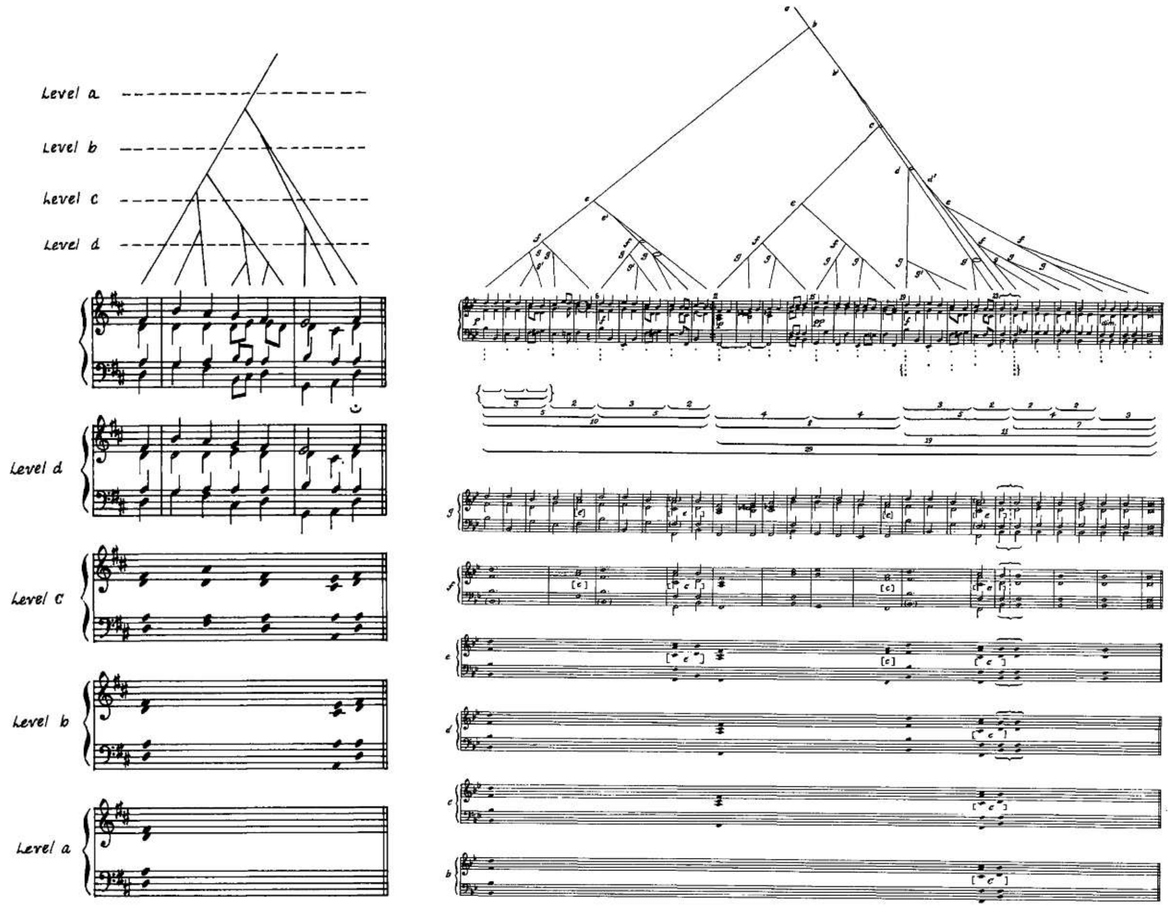


Figure 13: Prolongational reductions; Figures 5.8 and 8.33 from (Lerdahl and Jackendoff, 1983)

On the left hand side of Figure 13 one can follow the straight axis in the binary tree structure and see which musical note is more significant. The dashed level A, B, C and D correspond with the staves below. This usage of a binary tree does not only shows which musical notes are dominant, but also which musical notes in sibling branches should be made visible in case one want to revert the reduction one level by expanding. Therefore the position at which one axis merges into an other carries information. In expansion, like from the staves level C to D in Figure 13 musical notes might change duration but they keep pitch.

[BSC] Linguistic syntax trees mentioned in the previous chapter are also “headed” but the special visualisation possible in this music theory is intuitive to “read visually”. It shows the power of recursive reduction without the heavyweight linguistic concepts. This thesis author does not claim to have understood all the music theory due to a lack of background knowledge. Nevertheless the conscious approach by Lerdahl and Jackendoff exposes nicely the low level logic primitives and combinatorial representation. It shows a path how to transfer the techniques and tools across disciplines.

Gestalt

Lerdahl and Jackendoff explain connections between their music theory and Gestalt psychology:

> "The overall function of the preference rules is to select a structure that is maximally stable; that is, they define what assignments of structure to a musical surface are perceptually "good." Thus the preference rules in effect constitute an explicit statement of the Law of *Prägnanz* as it applies to musical perception." (Lerdahl and Jackendoff, 1983, p. 304)

They also see their principle of *preferential rules* reappear in similar principles in Vision research done by Marr. Gestalt psychology and Vision Research are the topic of the next chapter.

It should also be mentioned that in retrospective Jackendoff (2009) grants even more importance to his music theory work. We focused on *prolongational reduction* but it is only one of four structures Lerdahl and Jackendoff introduced, and only in parallel and together they can cover all parts of their music theory. This insight supports linguistic *Parallel Architecture*. The presence of four structures that describe the same piece of music is also again a difference to some linguistic theories that try to find the one syntax structure that rules everything. Though at a different scale, also in linguistics there are multiple notations for the same sentence for phonology, syntax and semantics like we have seen in Figure 9.

5.3. Vision Research

We will use the term *Vision* as the sibling-term of *Linguistics* when we reference these two research domains. The Glossary in chapter 2 documents what we group under the umbrella term Vision.

Seminal works like “Syntactic Structures” (Chomsky, 1957) (see chapter 5.1.1) introduced a new research programs around *generative grammar* in the sixties within language science and started a “Cognitive Revolution” in research. It was disruptive for Linguistics because it contradicted the then dominant view of *behaviourism*. A simplification of the idea of behaviourism is that the mind of a new born baby is a blank sheet and everything about language is learned from scratch[36]. One of Chomsky’s counterarguments was that our language capacity is actually *innate* and the mind of a new born baby is already prepared to learn any language. The knobs and sliders just have to lock into the right position to learn English, Russian or Chinese. The idea of innate capabilities was not invented by Chomsky and his peers. It is a reoccurring theme in philosophy. One group that was

36 This is really a simplification. Behaviourism is not essential for this thesis and is mainly mentioned to connect cognitive linguistics and perception research. They endeavoured from there.

pushed aside a few decades earlier by the behaviourism people was the Gestalt Psychology movement.

The Gestalt[37] psychology movement influenced the Vision researchers that we going to review next. Two thoughts from Gestalt are:

- 1) The laws of perception organisation are innate. This is a thought that Chomsky and his peers picked up, translated it to their domain of language and created a major research effort out of it: *language capacity*.
- 2) There are *a priori* rules and constraints that are in effect when we see something. These are the six famous Gestalt principles that are known as the law of Prägnanz (German word similar to *pithiness, conciseness, or terseness*) We will see some of the Gestalt principles later be picked up by Vision researchers like Biederman and Pizlo.

Gestalt psychology had its peek in a very unstable political time in 1930ties and 40ties.[38] Empirical research was a common method, but of course the tooling was not as evolved like it is today. The Gestalt psychologist did not further elaborated on certain of their findings like "simplicity" for perception. Though the importance of simplicity became apparent decades later in Vision research. In retrospective it can be seen as unfortunate because they were on a good track. Also much of their research was done before Shannon formulated *Information Theory* in 1948. Information theory defined the *concept of simplicity* in a new way and much of Prägnanz could be expressed in this novel way[39]. Overall the Gestalt psychology contributions to perception are considered significant (Pizlo, 2008, p. 44)[40].

The reader might recall that in the introduction chapter 1.2 we defined the term *building shape* with the help of the definition of *shape* and *form* from Rudolf Arnheim. He was a protagonist of the Gestalt movement. This thread allows us now to hook into research in Vision that have been done from the 1970ties up to today.

37 *Gestalt* is a German word and this origin is no surprise. Most of the historic figures related to the movement where German speaking. Many fled the Nazi regime and the term became common in other languages as well. Merrian Webster dictionary defines (not the theory but) the term Gestalt as: "something that is made of many parts and yet is somehow more than or different from the combination of its parts" (Merrian Webster Online, accessed 2017). This definition matches one of the famous catch phrases of the movement which originates from Aristoteles. But in German common spoken language Gestalt is a normal day to day word. Following the Duden (the leading German dictionary http://www.duden.de/rechtschreibung/Gestalt , accessed 2017) It can be used to describe: 1) the visible shape of a person, 2) an unknown person, 3) the projected public image of a person or 4) a form that has something special. So even in German the term Gestalt is strongly related to form and shape and can sometimes be used as a synonym for it.

38 Gestalt psychology is still an active research movement with conference and publication, but at a smaller scale.

39 This inspired a "neo-Gestalt" movement.

40 The Gestalt movement had also interaction with modern architecture and architecture theory which is not covered in this short section, which focuses on cognitive sciences.

[BSC] 3D shape perception is of interest for a wide variety of philosophers and researchers: Neuroscience, robotics, computer science, physics, mathematics, psychology, cognitive vision, etc..The research covered in the next sections with the term *visual perception* is just one of them. We will emphasise it because its ideas can be connected with the ideas from language science and the result could be of interest for architecture. Perception of architecture is currently by far not the commercial driver for this kind of research. Nowadays there are commercial interest in self-driving cars, robots that can interact within human made environments, optimizations for factories, augmented reality games, etc. The military is also interested in machines that can see similar to humans.

We will see that there are quite some strong opinions in this domain which are often in opposition to each other. The purpose of the overview is not to pick a side of an argument but rather benefit from their achievements. This is always driven by the desire to learn something for the task at hand: Building Shape Classification.

Similar to the domain of Linguistics the domain of Vision is highly specialized and different competing programs are present. The following sections do not try to cover the whole movement but will rather emphasise on a few Vision researchers and their ideas. Terminology is highly specialized and similar to other disciplines Vision researcher distinguish term very seriously which we as external observers might mix and match. The following summaries provided by the author try to paraphrase many statements in a way that are easier to understand for readers with an architecture background[41].

First we will review a few Vision terms which are central in the domain. Then we will discuss how important Vision researcher are in support or opposition to them. Some informal definitions might be:

- *Shape* – In Vision research when referred to *shape* it is always in the meaning of *perceived shape* not *geometrical* or *physical shape*. We have discussed this already in the introduction chapter 1.2 and we follow Arnheim's definition.
- *Shape constancy* – "when you view your car from a new angle, its image on your retina changes, but it is perceived as the same car. This fact defines what is called 'shape constancy.' Formally, 'shape constancy' refers to the fact that the percept of the shape of a given object remains constant despite changes in the shape of the object's retinal image. The shape of the retinal image changes when the viewing orientation changes." (Pizlo, 2008, p. 20)[42]

41 I hope this does not lead to unnecessary ambiguity and confusion were terms might not be used 100% correctly.

42 On Shape constancy. Pizlo has a further description of this Vision research specific term in his second book. The longer paragraph does a good job describing the concept in a simple way and therefore I like to quote it here as a whole:

- *Figure-ground organisation* – is one of the ideas from Gestalt psychology. It is the process by which the mind decides what is the *figure* to focus on and what is the *(back)ground* that is of lesser importance. The mind uses various clues like edges, size, shape, movement, colour to steer this decision.
- *Depth cues* – When we look at something we might have additional information at the moment of perception. This can come from the light rays hitting the retina like the surface shading, texture, contours, shadows, colours, etc. This can also come from the capabilities of the observers like binocular disparity, motion parallax / movement, accommodation, and vergence cues.
- *Veridical* – Like in "is shape perceived veridical?". It is a term that states that shape can be perceived as it is "out there". So it is a 3D perception of shape itself, not only of a number of *depth cues*.

We will look at contributions from the following researchers:

- Marr – Published a book with the title "Vision" (Marr, 1982) which was very innovative and influential for the next decades in his domain. Its effect is even called "Marr paradigm". Unfortunately David Marr died very young at the age of 35 at the same year. Other researchers carry on his legacy with their particular contribution weaved in. We will look only briefly at his work. His concepts avoided *figure-ground organisation* and preferred *depth cues*.
- Biederman – can be seen in a Marr tradition, but he incorporated findings from researchers that have not been influenced by Marr and also some ideas from the Gestalt psychologist like *figure-ground organisation*. His work is of special interest to this thesis because his main contribution is "Recognition by Components" (Biederman, 1987) and it contains a concept of *parts and components* as well as a set of about 36 geometric primitives. He discusses some of his concepts by analogy with similar pattern in Linguistics.
- Todd – is a researcher of the mainstream Marr tradition. He often collaborates with the established researcher Koenderink. He is of interest for this thesis because he contributes some findings about the perception of verticality and angles (Todd and

> "Naively, this does not seem to present a problem because we all know that all of the 3D objects in our physical world do not change their shapes unless we do something to modify them. But as soon as you realize that *all* of our information about what is present in our 3D world, beyond the objects we can touch, is conveyed to our brain by 2D representations on our retinas, it becomes difficult to ignore the problem raised by the fact that there are only 2-dimensions at our mind's interface with the external world. This inconvenient fact, which was established by Descartes and others more than 350 years ago, presents a huge problem because the shapes of the 2D images of all of the objects out there change as our viewing directions change when we move from room to room and from position to position within each room. But our perceptions of the shapes of all of the 3D objects out there do not change despite the changes of their 2D retinal images. This is the phenomenon called *shape constancy*." (Pizlo et al., 2014, p. 15)

Norman, 2003). He also wrote one of the major review publication that documents the state of the art of the mainstream in his domain (Todd, 2004). One of the mainstream assumption is that we rather see and need various *depth cues* and can not see shape *veridical.* The mainstream view has no commonly accepted solution how to explain *shape constancy* yet.

- Pizlo – came with a background of electrical engineering and geometry to the research of Vision. He is at opposition with the current mainstream view in his domain. He and his colleagues propose that humans can perceive shape *veridical* and they do so by using a surprisingly simple system. It is based on a few *a priori constraints* and the principle of *symmetry* takes a central role. They managed to implement their model in a working software system which sets them apart of their opponents. He is relevant for this thesis because symmetry is an important topic in architecture. Also buildings are usually constraint by things like laws of physics. Pizlo did publish two books that give an overview of the state of Vision research[43]. We will call Pizlo's approach "veridical Vision" to contrast and compare it to "mainstream Vision".

In the following sections each contribution will be summarized only in the parts that are of relevance for this thesis. In between the summary paragraphs there will be paragraphs which will try to connect back to architecture as well as to linguistics. We will continue the pattern from the previous chapters and mark the paragraphs which connect back to Building Shape Classification with the prefix "[BSC]".

5.3.1. Marr Paradigm

David Marr is considered as one of the innovators in his field. He anticipated to bring psychology as well as computer science views together to solve problems of human and computer vision with the same concepts. His work with Nishihara (1978) already showed ideas like hierarchical groupings, focus on axis and the use of an index or catalogue in the memory of our mind. David Marr died young at the age of 35. His monograph work "Vision"[44] (Marr, 1982) connects his findings and outlines a theory as well as a framework that could be implemented.

> Marr's formulation of visual perception was revolutionary. It contained so many insightful ideas that his approach was adopted by almost all researchers interested in space and shape

43 His books support his veridical shape theory, but mention most of the other views. Todd's review paper "The visual perception of 3D shape" (2004) is used to come to a balanced external view for the purpose of this thesis. Especially the later book "Making a Machine That Sees Like Us" (Pizlo *et al.*, 2014) tries to avoid the language typical and necessary in research paper publications for peers and tries to be attractive to readers from other fields. Though substantial parts of the project are already published in earlier publications like (Pizlo *et al.*, 2010)

44 Marr's book "Vision" was long in the making. It was actually published postume.

> perception during the last twenty years of the twentieth century. Marr's approach was so influential that it is usually referred to as "Marr's paradigm." (Pizlo, 2008, p. 95)

Marr emphasised that shape perception is the primary visual property and other properties like colour, shading, contours and texture are secondary to human vision. Still depth cues – including the just mentioned secondary properties – play an essential role and they are the helpers that *lead towards* or *help confirm* the perception of shape. Marr did not expect that one needs the Gestalt principles like *figure-ground organization* – formulated a few decades earlier – to solve the computational problems.

Instead Marr proposed three connected parts:

- first the primal sketch,
- in the middle a *2.5D* viewer-centric representation as a helper[45]
- at the end the 3D object-centric representation.

To handle the amount of visual information in a real world scene Marr and Nishihara propose a *recursive* modular system visualised with cylinders (see Figure 14). So there is essentially a model of *parts and composition*. Marr did not specify the composition model in detail.

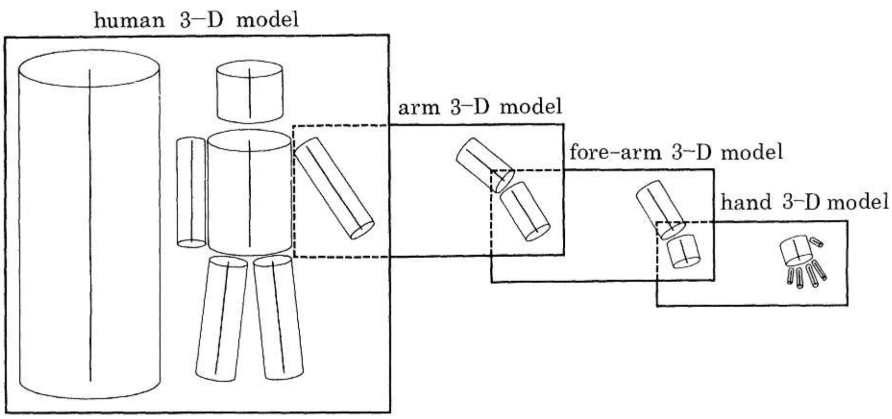


Figure 14: "Figure 3." from (Marr and Nishihara, 1978). A human model, that starts of a single vertical cylinder and then gets drill down to the arm, the fore-arm and the hand. All parts are modelled as cylinders.

[BSC] The use of a hierarchy that allows to reduce the complexity of perceived shape can be connected to the reduction of complex music to simpler notes that still carry the essence of the musical information by Lerdahl and Jackendoff as discussed in chapter 5.2. We can also identify parallels to geometry that deal with *(virtual) geometric shape*. Within commercial 3D computer graphics creation tools there are for instance two concepts: *Level of detail* and *subdivision surfaces*. Both concepts are used to solve problems in a pragmatic way: Declutter the computer screen so a human 3D artist

45 The 2.5D sketch deals mostly with perceived surfaces but not necessary 3D shape as spatial *volume*.

can concentrate on particular task and reduce the amount of computation resource to bring the pixels effectively on a screen.

Marr and Nishihara (1978) did not assume that we store a huge amount of 2D photographs of known objects like a chair in our mind, but that we rather have a lightweight 3D representation in-memory. So we have a kind of *index* or *catalogue* where we can look up a representation of perceived shape of an object. The index items have a simple *cone and axis* representation, while the index retrieval operation is a zoom in and zoom out pattern. The index retrieval operation allows to morph the aspect ratios of the cylinders so variations and similarities can be recognized. For instance the shape representation of a pony, a horse and an antelope are related. Figure 15 shows further examples of the morphing. Still we can distinguish these animals. Marr states that his pattern for the shape index might have parallel sibling systems, like a colour index and a texture index.

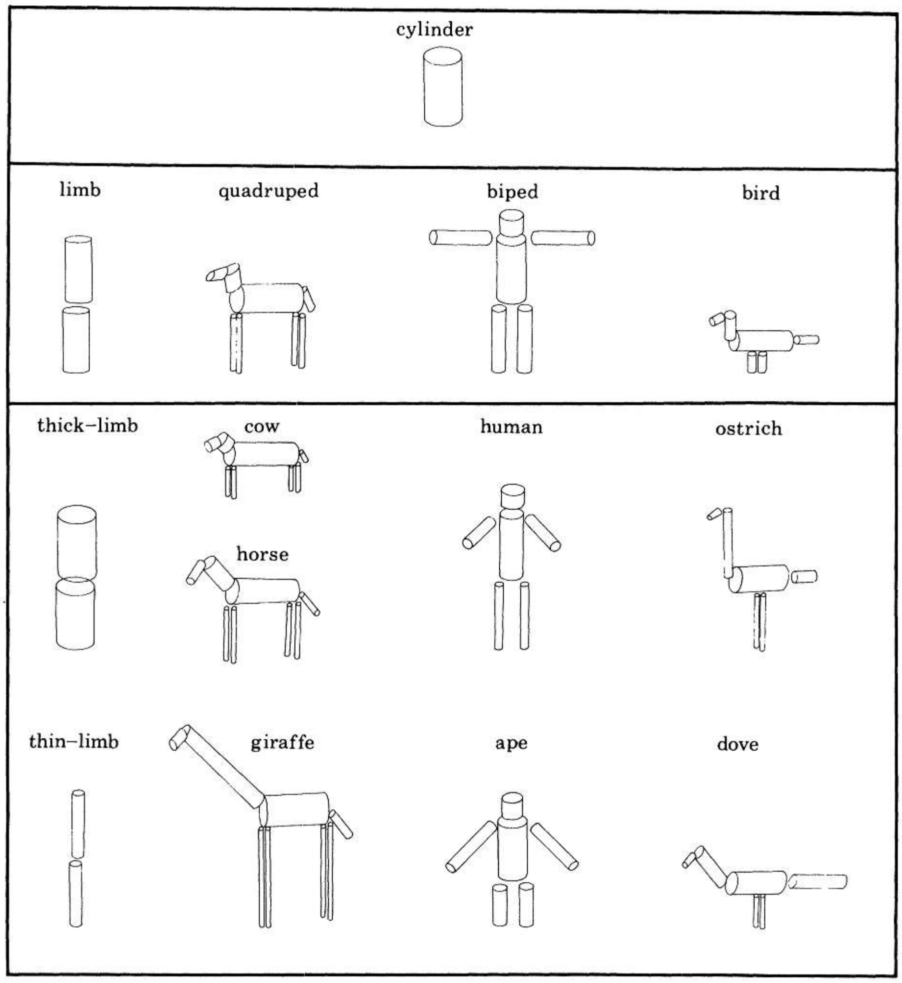


Figure 15: "Figure 8" from (Marr and Nishihara, 1978) A hierarchy of stick animals. A higher level item like *quadruped* is idealised in its proportions, and the arrangement is more important at this level. In deeper levels the proportions of the parts are changed and the idealised figure morphs into more specific shapes like a cow, horse or giraffe.

[BSC] This index plays a similar role to what linguists usually call a lexicon. Marr's work is also mentioned in the publications of linguist Ray Jackendoff whom we have covered in earlier chapter 5.1.2. In “In Defense of Theory” Jackendoff also proposes that the pattern for various human faculties like language and perception might be build upon the always same repeating operational and organizational pattern (Jackendoff, 2017, p. 4). So there is some general awareness between linguistics and vision research as we will also see later with Biederman. Of course having an index, a lexicon or any other system that helps comparison could benefit this thesis about building shape classification.

5.3.2. Biederman’s Geons

Linguistics

Biederman main contribution is known as “Recognition-by-Components” (RBC) (Biederman, 1987). He introduces his system tailored for Vision perception as an analogy of speech perception from language science. He paraphrases the quote from Humboldt: “makes infinite use of finite mean” which Chomsky made famous. Biederman’s analogy becomes:

> “The hypothesis explored here is that a roughly analogous system may account for our capacities for object recognition. In the visual domain, however, the primitive elements would not be phonemes but a modest number of simple geometric components – generally convex and volumetric – such as cylinders, blocks, wedges, and cones. ... RBC [Recognition-by-Component] seeks to account for the recognition of an infinitely varied perceptual input with a modest set of idealized primitives.” (Biederman, 1987, p. 115 & p. 122)

In contrast to Lerdahl and Jackendoff’s approach to music (see chapter 5.2), Biederman is not referring to the syntactic structure of sentences but to the *phonemes* which are the sounds that we perceive with our ears and transform them into words, then into sentences and then into thoughts. It is not surprising that a researcher from Vision is especially interested in the perception of sounds that become words. Biederman notices that the perception of the typical 55 phonemes is actually a *simpler* task, because the number of dimensions is just one. We can hear one phoneme after the other and therefore distinguish between the words “fur” and “rough” and once we perceived them as a group we can look them up in our in-memory lexicon. The perception of shapes in a similar way will require a lot more processing. Each spatial dimension adds possibilities where one can attach yet another geometric component. For Biederman this is actually not a limitation but a feature of his approach. The high number of individual shapes that one could describe with just three, four, five, etc. of his geometric components composed together would allow one to represent the many shapes that we can identify in nature when we look at our environment[46].

Biederman and Marr

To a certain degree Biederman's theory can be seen in a tradition of the *Marr Paradigm*. He picks up some points where Marr left. As mentioned above Marr and Nishihara proposed a recursive modular system where a human perceives shapes as hierarchical combination of parts and composites, but they did not give many details how this arrangement can be described for complex objects. Biederman tries to formulate this arrangement system and he describes in more detail how one can recognize that one part ends and another begin by focusing on areas of deep concavity.

There are also some significant differences to the Marr Paradigm in Biederman's work. He proposes that his volumetric primitives can actually be *perceived and identified* from various view points by their 2D image without the need of the 2.5D sketch that Marr requires. While Marr focused on surfaces that make up the volumetric parts in a later stage, Biederman works more directly with volumetric parts. The parts can be specified by their two dimensional image properties. Biederman achieves this by utilising a lot of *simplicity principles* and a *figure-ground organization*. Both are tools from the Gestalt theory era that Marr did consider as unnecessary. Marr instead use a lot of depth cues which are not present in Biederman work. Biederman uses simple line sketches without any shading, texture or colour, which are typical depth cues.

[BSC] We can connect this back to building shape. In communication on unbuild architecture projects and in engineering the line drawing is one of the most often used communication techniques among peers of the same profession. A shaded and coloured representation is usually called *rendering. A rendering* is often used to reach out to clients and the public. It might be that the line sketch is often sufficient for communication partners that are mostly concerned with construction problems. Such problems are usually three dimensional and require geometric and volumetric thinking. Today technical progress like 3D modelling tools and viewer software that allow rotation and zooming of models changes this. Digital renderings and processes like BIM enhance the traditional line drawing. The rendering – once a time intensive asset – becomes a commodity.

Biederman is especially interested in the *primal access* of an object. He focuses on what is possible first, by showing his participants stimuli pictures for only 100 milliseconds. He

46 The analogy to linguistics is not only used in his introduction as an entry point, but he picks it up at some point in his main argument and again emphasises it in his conclusions. Biederman was not the first to connect language perception and shape perception, but he was the first one to create a theory and supports it with empirical experiments. (Pizlo *et al.*, 2014, p. 146)

recognizes that something called *mental rotation* was also performed by his participants but that is was quite expensive and often outside of the primal access within its 100 milliseconds. The use of mental rotation is something that differentiates Biederman from Marr[47].

[BSC] Buildings are usually quite big and we are most likely used to perform a lot of these mental rotation task when we look at them.

Geons

In Biederman's setup of *parts and aggregates* the parts consist of a group of approximately 36 *Geons*. The term *Geons* is an invented word by Biederman and stands for "geometrical ions". The members of this set of "just 36" are not arbitrary but derive from certain conditions. The conditions enumerated by Bierderman are: collinearity, curvilinearity, symmetry, parallelism and cotermination. Each one has been researched before in Vision research and was considered important for shape perception. Simplified explanations of the five terms are:

- *Collinearity* – We assume that perceived straight lines are also straight lines in their physical form.
- *Curvilinearity* – We assume that a perceived smooth curved line is also a smooth curve in its physical form
- *Symmetry* – We assume that perceived symmetry is also present in its physical form
- *Parallelism* – We assume that perceived parallel lines are also parallel lines in their physical form.
- *Cotermination* – We assume that edges which look like they meet each other as a point do so in their physical form as well.

47 The research on mental rotation was done a few years earlier in parallel to Marr and these researchers have not been influenced by the Marr Paradigm (Pizlo, 2008, p. 144).

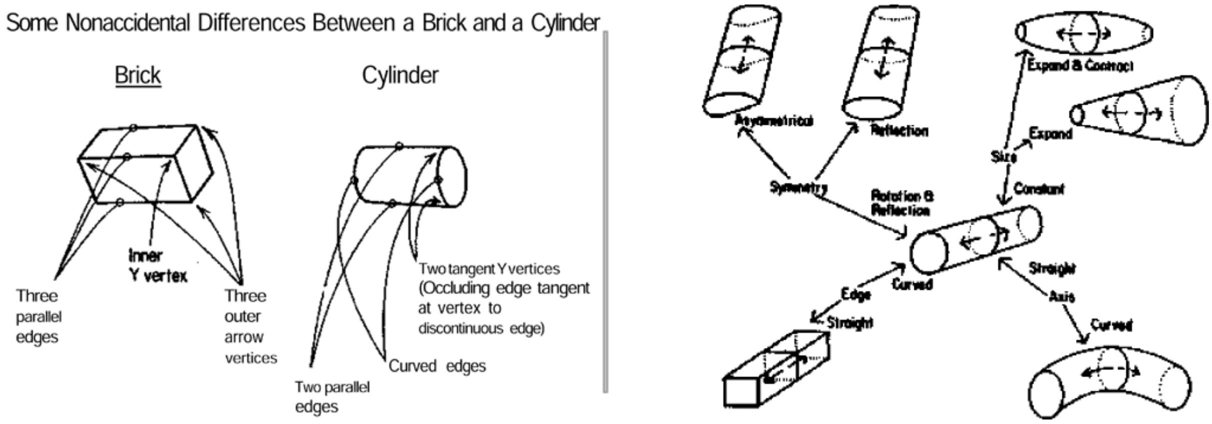


Figure 16: Left "Figure 5", right "Figure 6" from (Biederman, 1987). The right hand side shows the various transformations of the cylinder in the middle. This makes Biederman Geons more diverse then the simple stick figures from Marr and Nishihara

There is a repeating pattern here. We assume that what we perceive is simple and is not a visual illusion. These properties have in common that they are non-accidental: "they would only rarely be produced by accidental alignments of viewpoint and object features and consequently are generally unaffected by slight variations in viewpoint." (Biederman, 1987, p. 119). These are *simplicity principles* similar to the thoughts of Gestalt psychology that Biederman introduces at this point. Contrary *visual illusions* are accidental and are very seldom in real nature. We will see that there is some controversy about this topic later with Todd and Pizlo.

[BSC] We can reflect the *illusion* topic back to architecture. It is possible to create visual illusions in real buildings. But the existence of some very few of these illusions does not repeal the simplicity principles which are valid for most of our natural and built environment. Architects sometimes deliberately try to use such illusions to challenge the users of their buildings and create spatial effects. So it is a design decision to break some simplicity principles.

To make his Geons easier to communicate, Biederman is reusing terms we are all used to. So he calls some of the Geons: cylinders, block(/brick), wedges, and cones. It is easier for the reader to follow. We briefly skip the cone, as it is related to a cylinder and the wedge which seems to be special. We have now two Geons, the cylinder and the block, that can easily be distinguish by their cross sections(1): circular sections of cylinders and square sections of blocks.

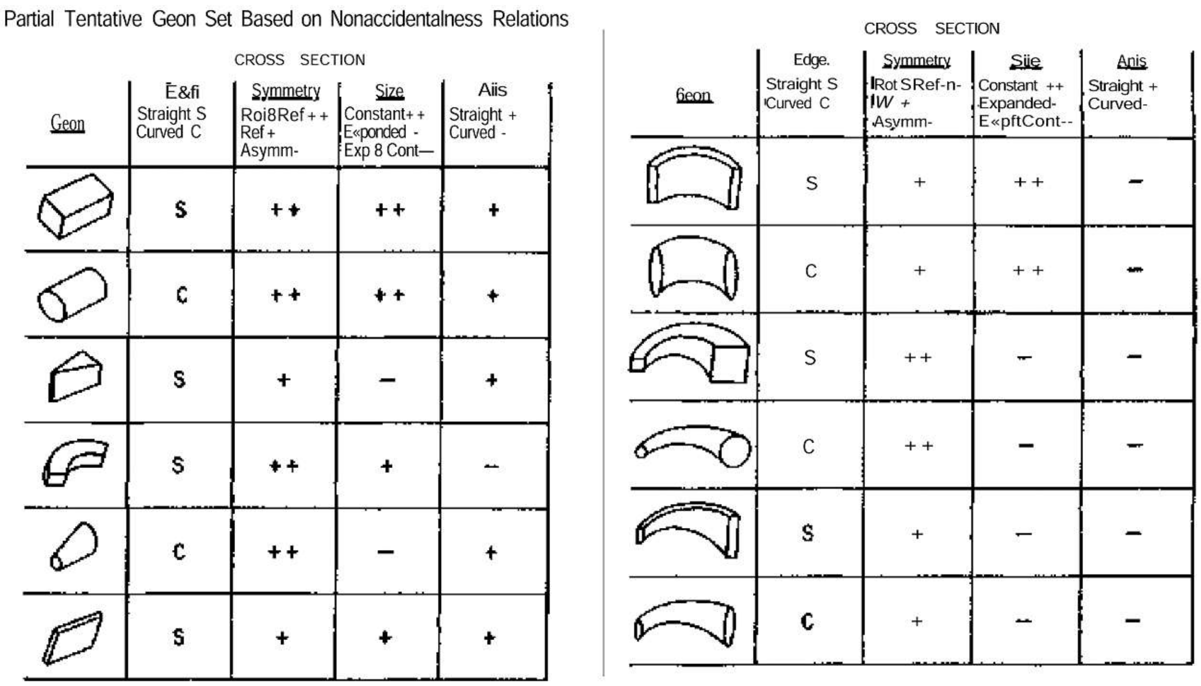


Figure 17: Left: "Figure 7"; right "Figure 9" from (Biederman, 1987) show how different transformation are applied and form a set of shapes. Its interesting to see that there are different intensities of transformations symbolized by "++, +, - , --"

The two Geons can be transformed to create related members:

- (2a) We can have strong symmetry in the cross section like with a circle or a square
- (2b) We can stretch one of the axis and have a cross section of a significantly stretched ellipse or a significantly stretched rectangle
- (3a) We can leave the size of the cross section constant
- (3b) We can *expand* and then again *contract* the cross section while it is swept along the axis
- (3c) We can *contract* and then again *expand* the cross section while it is swept along the axis
- (3d) We can scale the cross section to/from zero while it is swept along the axis which leads to cones and pyramids
- (4a) We can leave the axis straight
- (4b) We can bend the axis on which the cross section is swept.

We see that with the properties of (1), (2), (3) and (4) it is possible to create a matrix with 32 members (2 x 2 x 4 x 2) and we can add special cases of wedges. Biederman is referring to 36 Geons at various places throughout his paper.[48]

48 It might be that I have misunderstood the used of the *wedge*. The only example in "Table 7 row 3" can only be achieved when the scaling on the cross section is not constant at both axis, as described in bullet point (3d). When we would put this up as a fifth bullet point "(3e)" we would end up with 40 members: At one point Biederman is a bit vague and uses the word "or" in the operations: "From variation over only two or three levels in the nonaccidental relations of four attributes of generalized cylinders, a set of 36 geons can

Biederman also observes that many natural and man made object that have a transformation like bullet point (3d) do not have a pointed tip but rather a truncated or rounded one. So he adds the following secondary rules for component terminations:

- (5a) leave a sharp pointed tip and have cones or pyramids.
- (5b) stop scaling at a certain point and have a truncated tip instead of a pointed one.
- (5c) stop scaling at a certain point and add a rounded tip instead of a pointed one.

The observation that tips of objects might have special geometry is also elaborated by the “IL 22” book which we will review later in chapter 5.4.2.

All of theses Geons are referred to as *generalized cones* The term *generalized cones* is used less strict in Vision science then in mathematics. While the mathematical/geometrical definition requires a flat surface, the use in Vision science considers the flat surface members as special members of a broader group. The basic idea is that the geometry can be constructed by “sweeping” a cross section along an axis. The objects that are created by this operation usually have translational symmetry. When they are simple, they can have mirror symmetry and even rotational symmetry. Vision researchers are actually quite interested in having an axis which might also be bend, so their definition of axis is also a bit looser then in mathematics. By having things like bend axis, contraction and expansion one can model many 3d geometries that we can be identify in nature and man made objects.

[BSC] In architecture practice there are software tools which can create NURBS[49] surface geometries. One available construction method for a NURBS surface is a *sweep* along curves that are guides for certain checkpoints on the cross section. The geometries of the Geons are not so “exotic” for contemporary architecture. Biederman set of 36 Geons is very reduced and in architecture as well as many other design fields we can see many more complex and often asymmetric shapes. This must be seen in the context in which Biederman picks his candidates: he is interested in perception not construction. He is mostly concerned with *primal access within 100 milliseconds* and he states that all the other shapes do of course exist but can not be recognized without some expensive mental effort. Architects might very well deliberately pick these more complex shapes as a design decision to let their users

be generated” (Biederman, 1987, p. 121). So he might have dropped some seldom combinations like the 4 theoretical circular wedges to reduce the number to 36. He references the sphere in a few sentences but it is not clear if it is part of the 36. It is a bit surprising though that it is not possible to find a picture with all 36 Geons visualized at once. This picture might very well exist, but Biederman paper is cited more then 6000 times according to a platform like Google Scholar so its hard to figure out where to look for it. Biederman is also not certain if 7 additional planar two-dimensional components should be added to the set of 36 volumetric and decides to skip them. (Biederman, 1987, p. 125)

49 Non-uniform rational B-spline (NURBS)

reflect about the buildings they have designed. The price of having to look more then 100 milliseconds to understand the building shape is acceptable when we spend a lot of time using the building. Might the usage time be minutes, hours or even years.

Composition

Biederman's paper does concentrates on the "particular vocabulary of components", though it also provides a small section how these components could be composed with each other. "Two different arrangements of the same components could produce different objects." (Biederman, 1987, p. 116) The arrangement properties are a surprising small list:

- Relative Size – 3 values: A > B, A = B, A < B
- Verticality – 3 values: top, bottom, side. Biederman speculates that these values are sufficient for about 80% of objects.
- Centreing – 2 values: end-to-end (off centre) or end-to-side (centred). This is observed where two two objects meet. Biederman states that in most cases there exist an end-to-side situation, which leads to two concavities. These concavities are important as they are the cues for the observer where new parts start.
- Relative size of the surface at join – "Other than the special cases of a sphere and a cube, all primitives will have at least a long and a short surface. The join can be on either surface" (Biederman, 1987, p. 128).

The presence of two concavities (cusps) can be observed for example where the arm attaches to the torso, fingers join into the palm, or a table foot is attached to a table plate. Indeed we can identify many of these kind of joins in our environment. Often the non-accidental property of curvilinearity discontinues. Based upon (Marr and Nishihara, 1978) Biederman uses this phenomenon as his main operation to identify different parts. Biederman is aware that the system is not perfect and brings up the example of a pencil and its tip. The pencil could be modelled as a cylinder where a cone is attached. He explains that in these cases the missing concavity at the join might be compensated by differences in other above mentioned non-accidental properties. So for instance the cylinder has parallel lines, while the cone has converging lines. Though these are weaker indicators then the concavities.

[BSC] The problematic example of the pencil, could also be transferred to a house. A simple house with a gable roof might have the same pattern. But in reality many such gabled roofs have eaves which serve as rain protection, so the concavity is present again. One common criticism of the Recognition-by-Component theory is, that it is hard to distinguish between an apple and a pear. A task that is pretty easy for a human. The pear has what architects would usually call a *blob* like shape. While not omnipresent, these kind of organic shapes are appearing in contemporary architecture.

The above mentioned verticality is quite reduced. It does not distinguish between left, right, front and back but rather calls all these arrangements “side”. Top and bottom are of more interest for Biederman, because a lot of animals and humans have a head that sits on top of a torso and the legs are below. The term verticality transports also the fact that gravity is the main influencer. We will see the concept of verticality later reappear in this thesis under the name *orientation*.

Even with this very reduced system for composition Biederman can compose 74694 possible objects with two Geons and 154 million with just three. He sees this as a positive feature of his theory because of the vast amount of shapes we can identify in our natural and man made environments in everyday life. Therefore composition of smaller parts becomes an accepted approach to distinguish objects by their shapes. (Todd, 2004, p. 118)

The purpose for the recognition of the parts and the composition is to look them up, or compare them to, with some representations that we already have in memory. Biederman assumes that his approach of Recognition-by-Component is more promising then (Marr and Nishihara, 1978) which mainly uses aspect ratio of similar looking animal figures made out of linear elements (see Figure 15). Marr and Nishihara emphasise on the axis of the animals. The general idea of an index is similar in both papers. Aspect ratio, which is usually called *proportion* in architecture, is known within Vision science to be ambiguous and hard to judge correctly by a human observer.

[BSC] Biederman sees also the possibility to calculate a similarity value between two shape representations (Biederman, 1987, p. 122). This is something that we will also try to achieve for building shapes in chapter 9.

The Theory in Context

Biederman is referring to the Gestalt organizational principals, which Marr considered unnecessary for the task of shape perception:

> As suggested by the section on generating geons through nonaccidental properties, the Gestalt principles, particularly those promoting Pragnanz (Good Figure), serve to determine the individual geons, rather than the complete object. A complete object, such as a chair, can be highly complex and asymmetrical, but the components will be simple volumes (Biederman, 1987, p. 126)

From this quote we can obverse that Biederman explicitly limits the Gestalt principles onto his Geons. Not at the potentially more complex composition itself.

Later research of Biederman will give indications that shape perception might be to some extend *veridical* and he can back this with empirical data. The topic of veridical shape perception is controversial within the domain. Important researcher like Koenderink and Todd started to some extend follow his finding. But they did not fully embrace the Geons and the Recognition-by-Component.

In retrospective Recognition-by-Component is problematic with real images of every-day objects though:

> Biederman's (1985) RBC theory forced visionists to change the way they thought about 3D shape perception, but the theory itself did not lead to computational models that could be applied to real images of real objects. No one to date has succeeded in providing an algorithm for finding geons in real images. (Pizlo, 2008, p. 132)

Biederman concentrated on a set of 36 generalized cones. There was a similar independent research by Pentland (Pentland, 1986) that focused on a set of 56 superquadrics. Pentlands research was further refined by Dickinson who tried to incorporate some of Biederman's concepts. We have already heard of superquadirics in the introduction about the fuzzy shape database Zhang (Zhang, Pham and Chen, 2002). These geometric objects have the special characteristic that they are driven by a handful of decimal parameter which allows fluent transition from one to the other. These makes them attractive to *computer vision* researchers. "An approach to 3D shape recognition, based on Pentland's superquadrics, was somewhat more successful." (Pizlo, 2008, p. 135).

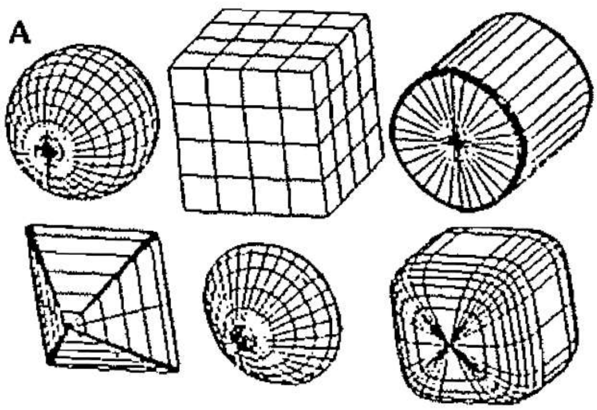


Figure 18: "Figure 3.a" from (Pentland, 1986) showing different superquadrics all based on the same algorithm but with different properties that transform the shape.

Biederman confirms findings of colleagues that symmetry is important (page 4) and that asymmetrical patterns require more time to be identified (page 9). We will see later in the section about Pizlo that symmetry can have an even more exposed role in shape perception.

[BSC] The contribution of Biederman is a whole theory and the Geons are only one part of it. But the 36 Geons based on generalized cones as well as Pentland's 53 superquadrics have in common that they try to describe shapes as volumes by use of geometry. So they really try to match or at least approximate the 3D points in the physical world. This leads to a tricky question: When we as observers seek more detail, then more Geons must be added to the shape that we want to recognize or compare. For instance humans do vary in height, width and colour but the main geometries are nearly always present: Torso, head, arms and legs. So we also recognize humans by smaller geometries like their noses and their eyes. In the case of a human we might decide that the Geons that characterize the face should always be included. This is possible because most humans look alike. When we start to look at objects which varies much more in their physical geometries it becomes more tricky. For instance architecture buildings like the World Exposition pavilions, that we will examine later in this thesis, are much more diverse. Sometimes small parts of the buildings *geometry* characterizes the *building shape*.

[BSC] The *parts and composition* aspect of Biederman's theory is something that we can very well observe in buildings. Parts and composition is the base how the architecture and construction industry constructs buildings for thousands of years. But here we try to find out if we recognize and can compare whole building by the fact that they consist of more then one distinct building part.

[BSC] For instance twin high rise buildings like the former World Trade Center in New York. Each of the two towers had a very simple building shape by itself. But the composition of two of these towers made them recognizable. We can ask if the New York towers had something in common with the Petronas Towers in Kula Lumpur. The Petronas Towers have an octagonal floor plan and they get narrower towards the top. Strictly speaking it is not the geometry that connects the two buildings but arrangement properties and proportions.

5.3.3. Todd and Depth Cues

Todd can be seen as a researcher in the mainstream Marr tradition. He shares Marr's point of view that one major milestone for vision research would be a computational algorithm that works identical to the human brain (Todd and Norman, 2003).

In a major review paper of the state of Vision research (Todd, 2004) he points out that there is some consensus that human perception mostly works on *qualitative* instead of *quantitative* properties. Empirical results show that people can reliably determine *qualitative* properties, like curvature from visual information . Mainstream researchers suggest that lower order geometric properties and topological relationships are compensating for our lack to perceive metric relations well .

Most empirical research on *quantitative* properties suggest “large systematic errors in observers’ judgments of 3D metric structure” (Todd and Norman 2003)(page 11) and that “judged metrical relations almost always deviate significantly from the physically specified structure, and they are often unreliable as well” (Todd and Norman, 2003). This is also a position that Biederman holds as he reports that:

> The high speed and accuracy of determining a given nonaccidental relation (e.g., whether some pattern, is symmetrical) should be contrasted with performance in making absolute quantitative judgments of variations in a single physical attribute, such as length of a segment or degree of tilt or curvature. For example, the judgment as to whether the length of a given segment is 10, 12, 14, 16, or 18 cm is notoriously slow and error prone (Biederman, 1987, p. 121)

[BSC] For building shape classification this is an important insight. Due to the task of erecting a building the architecture and construction industry is bound to use quantitative metric information as a major way to communicate. But according to Vision researchers, for the users of the buildings the visual perception of metric information seems to be difficult. The architecture curriculum invests resources to study proportions and it is assumed that not only the architects will recognize them but also the lay user will find them *pleasing*. Above findings from Vision research should not repeal the use of things like proportions within architecture, because the basic tasks are quite different. A person using a building and a person studying the visual appearance of a building are doing two different things. Similar we can quickly identify how many persons are depicted in an oil painting or we can spend more time and study the picture and try to interpret what the artist wanted to communicate with his work. Still the quick perception task is always first and we might not have the indent to study the buildings that we are using but rather try to achieve other day to day goals. For instance many factory building pay little attention to details while representational buildings usually show “architecture”.

Todd points out that there is more to perception then the depth cues that hit the retina via light rays. The observer has capabilities like binocular vision and can process more then one shape representation of an object:

> These include apparent motion sequences with three or more distinct views [6] and binocular displays with both horizontal and vertical disparities [7]. Because motion and stereo are such powerful sources of information, especially when presented in combination [8], it should not be surprising that they are of primary importance for the perception of 3D shape in natural vision. (Todd, 2004, p. 116)

[BSC] As mentioned in the introduction we follow Arnheim's definition and *perceived shape* is the sum off all experiences that we have with an object, therefore motion and distinct views are providers of multiple slightly different picture of the same shape.

Vision research is often focused at the primal access and reaction times because it can be setup and measured well in empirical experiments. The mainstream Vision researchers also try to setup empirical experiments where only a single human capability is tested at a time. For instance perception of the depth cue of curvature. The setup of these experiments tries to eliminate all other depth cues from the stimuli image. This often leads to amorphousness and very unnatural looking stimuli pictures. See examples in Figure 19 and Figure 20. The surprising result of many of these kind of experiments is that humans have many problems with perception. But in our day to day life we can handle all of these with little effort. This leaves the important topic of *shape constancy* an unsolved problem for mainstream researchers. Mainstream researchers also question their colleagues works by pointing out that there might have been other depth cues that interfered with the one that they tried to measure.

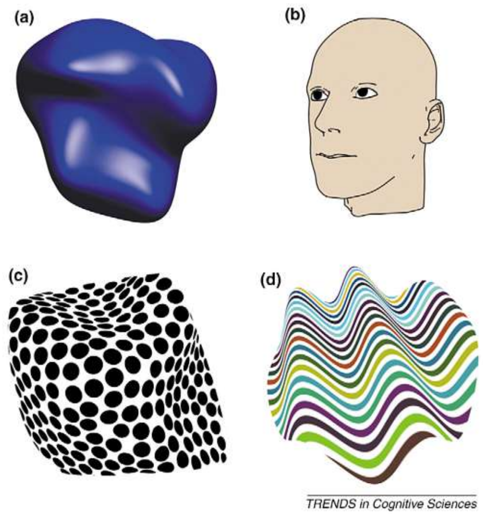


Figure 19: Experimental stimuli pictures as used in empirical Vision research. (Todd, 2004)(page 1, Figure 1)

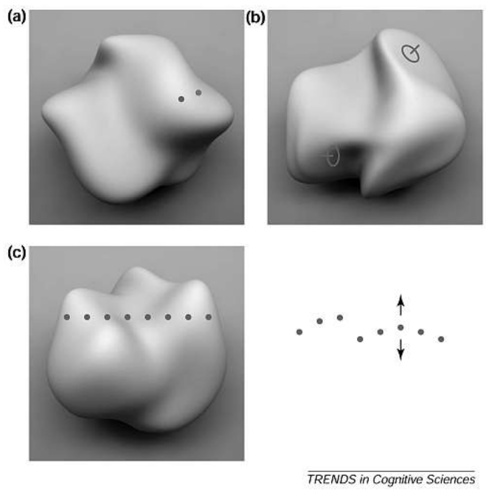


Figure 20: Amorphous stimuli objects which only uses shading as a depth cue. (Todd, 2004) (page 3, Figure 3)

The mainstream methodology – represented here by Todd's review paper – is strongly questioned by some researchers like Pizlo (2008, p. 118). Pizlo argues that by using ambiguous illusions in artificial stimuli images these researchers are missing the point that the human perception is tuned by nature to perceive the simple unsurprising thing and not visual illusions which hardly happen in our day to day life. Pizlo also questions the focus of mainstream researchers on *surface* instead of 3*D shape/volume* which he sees rooted in the Marr paradigm. (Pizlo, 2008, p. 144)

More recent Vision research suggests that it is possible for humans to perceive metric information more accurately when the user interacts more with the object. For instance three or more significant changes in perspective allow for better metric judgement (Lee *et al.*, 2012). This can be achieved by rotating an observed object or by looking at photograph taken from different point of views.

[BSC] The use of photographs from different point of views is a typical approach to communicate architecture. This is also something the empirical part of this thesis will utilise. Though one should keep in mind that the ultimate use of a building is not to be looked at in photographs but actually be used by humans. We can rotate a small object like a pear in our hand, or quickly walk around a statue, but buildings are usually larger. Humans that are on a building site are bound to gravity and time. Usually they can not get an aerial view of a building and only look at the building from points where access is possible. Humans need time to significantly change their position and therefore point of view related to a building. They might need a minute to walk around a building. We can not assume that the lay persons only objective is to finally understand the shape of the building that they are visiting. Keeping vague metric information in-memory and memorizing them while users spend time changing their point of view significantly is also most likely an error prone task.

[BSC] While it might be a desirable setup for empirical Vision to just look at a single depth cue it is hardly the fact for building shape. There are always multiple depth cues present in the photographs or for a persons on the building site. Buildings are part of the real world and not part of laboratory set-ups. Therefore there are plenty of additional context objects in the background that suggest scale and slant. Even Vision researcher agree that the more independent depth cues and context object we have the better the correct perception of qualitative *and* quantitative properties.

Are the findings from Vision research of little value to architecture because at the end we will see all the metric details anyway? Cognitive sciences agrees that the human brain tries to optimize calculations and wants to invest the minimum amount of effort into the tasks at hand. Therefore we can assume that the low effort quantitative feature will be very likely recognized while the higher effort qualitative feature will be used a bit more reluctant, mainly in situation where the qualitative feature deliver not enough information to make decision.

5.3.4. Pizlo and Veridical Shape through Symmetry

Pizlo came with a background of electrical engineering and geometry to the research of Vision. He and his colleagues propose that humans can perceive shape *veridical* and they do so by using a surprisingly simple system. It is based on a few *a priori constraints* and the concept of *symmetry* takes a central role. As mentioned in the introduction chapter 1.2

Pizlo and his colleagues adapted the definition of *shape* so it works for their task: to create a working computational model.

He describes the roles of *a priori constraints* as follows:

> [...] the fact that the successful functioning of the human visual system depends on a number of abstract, but very effective a priori constraints (operations built-in to the visual system and elaborated throughout its evolution). It is surprising, but true nonetheless, that these a priori constraints are often more important than adding additional visual information. (Pizlo *et al.*, 2014, p. 3)

[BSC] World Exposition Pavilions also have things in common that we already transport with the word "building". We can not make the same strong statement like the Vision researchers and claim that this is *innate* but it is strongly cultural normed. Calling something a *building* usually implies it is meant to be used by humans. We assume that a building defines space and provide shelter from the environment. We assume a certain scale range. Calling something a *pavilion* triggers additional cultural expectations.

Veridical

> Using a priori constraints permits the veridical perception of 3D objects and 3D scenes. Saying that human perception is veridical simply means that human beings see the 3D shapes and scenes in the physical world as they really are "out there." (Pizlo *et al.*, 2014, p. 3)

The assumption that we see shape *veridical* and that *shape constancy* can be achieved (Pizlo *et al.*, 2010), puts Pizlo at opposition to the mainstream view in Vision research. Pizlo did not invented these terms or concepts. They were already present in prior research. For instance the acceptance of mental rotation by Biederman can be traced back to earlier research (Biederman, 1987, p. 140). The importance of *a priori* constrains is attributed by Pizlo to Perkins in the seventies. So Pizlo and his colleagues' work is an evolution of existing ideas. But they claim that they achieved to create a computational model, which sets them apart from the mainstream view. The mainstream view still struggles to handle *shape constancy*.

Symmetry

Pizlo focuses on symmetry as the most important *a priori constraint*. He manages to connect the important concepts "veridical <-> symmetry <-> shape constancy" with his approach:

> "Second, we know from our work on the recovery of the shape of a 3D object from only one of its 2D images (described later) that 3D symmetrical objects can be recovered veridically from a single 2D perspective image. The shape recovered is said to be _*veridical*_ because it is the same as the object's shape out there. But 3D objects devoid of symmetries cannot be recovered from a single 2D perspective image, which means that amorphous objects cannot provide us with useful information about conditions in our visual world. Symmetry, which is ubiquitous in our visual environment, plays a critical role in the veridical recovery of 3D shapes, so it is symmetry that provides the basis for the perceptual achievement called _*shape constancy*_." (Pizlo, 2008, p. 11).[51]

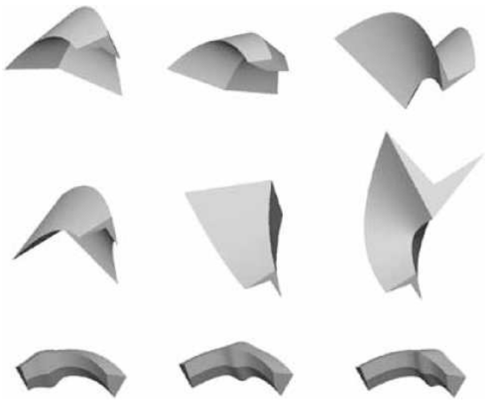


Figure 21: shapes that contain shading and symmetry (Pizlo *et al.*, 2014) (page 12, Figure 1.8)

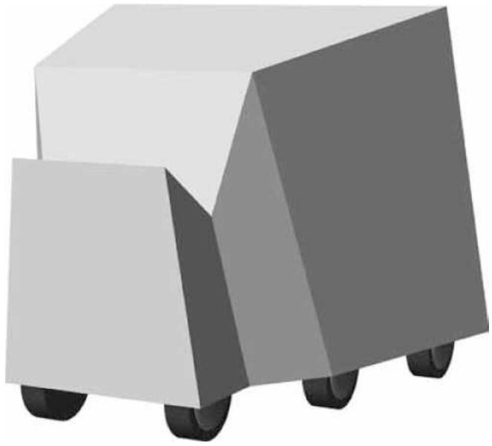


Figure 22: A simple lorry (Pizlo *et al.*, 2014) (page 55, Figure 2.1)

Recognition of symmetry becomes central and it is *innate*. Pizlo clarifies that this includes three types of symmetry similar to Biederman:

- Mirror symmetry like in the human body
- Rotational symmetry like in flower blossoms
- Translational symmetry like in stems of flowers and limbs of animals

In Vision research, symmetry is not as strictly defined as it is in Geometry. For instance the human body is considered mirror symmetrical, even though me know that human faces are not strictly symmetrical. Rotational symmetry like in flowers allows for irregularities due to the organic nature and environmental effects. Translational symmetry was already mentioned in the section on Biederman. Pizlo points out that even when the stem of a flower bends in the wind the symmetry of the section still exists. "If an object is piece-wise rigid, like the body of a dog, changing the articulations of its legs distorts the mirror-symmetry of the dog's body, but it does not eliminate the symmetry altogether." (Pizlo *et al.*, 2014, p. 11). Humans recognize this symmetry without much effort.

51 *Shape constancy* becomes then the hook for the operation definition of shape which accompanies the analytical definition of shape which we have covered in the introduction of this thesis. "Our *operational definition of shape* states that there are no stimulus properties that can be attributed to shape beyond those that can be demonstrated in a shape constancy experiment. Said succinctly, shape constancy is the sine qua non of shape (without which, there is no shape)" (Pizlo, 2008, p. 13).

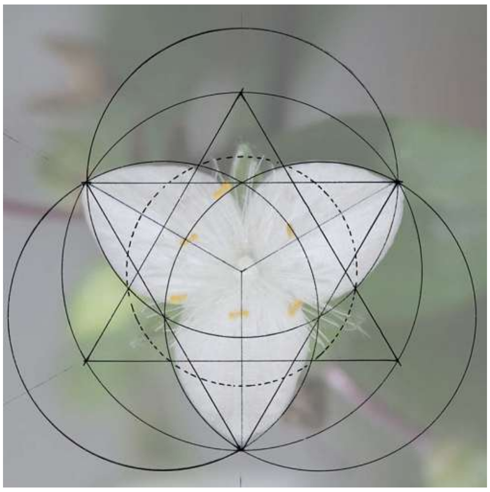


Figure 23: Complex symmetry arrangements from "The Hidden Geometry of Flowers" (Critchlow, 2011, p. 215)

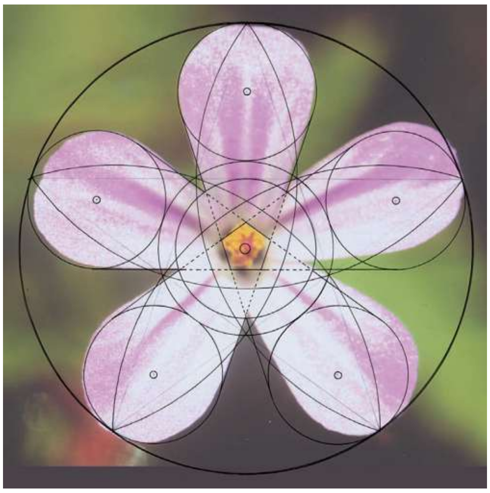


Figure 24: Complex symmetry arrangements from "The Hidden Geometry of Flowers" (Critchlow, 2011, p. 225)

[BSC] Symmetry is of course present in many architecture buildings, and the three symmetry types are well known tools in the repertoire of architects. Sometimes they are used as a very strong design statement but often the building composition as a whole, including its annex parts and openings, is not strictly speaking symmetrical in a geometric sense. When we look at distinct building parts we can often find further symmetry. Symmetric operation are common during the CAD phase of buildings. Though to be useful for building shape classification symmetry must be used in a less strict way similar to Vision research.

Shape recognition is not a goal by itself but a mean to start an efficient search of the human memory to act meaningful.

> A modest, finite number of parts can be used to compose addresses for an almost an endless number of objects. Some readers have surely noticed what Biederman (1987) pointed out in his paper - that this scheme is analogous to the way only 26 letters in our alphabet can be used to form an endless number of sentences. Biederman's idea was great, but nobody to date has been able to make it work for shapes.
>
> We think that we have a better idea, an idea that might actually work. It is based on our definition of shape, which makes use of an object's symmetries. "Symmetries" might work much better than "component parts" for modeling a content-addressable memory of shapes." (Pizlo *et al.*, 2014, p. 219)

[BSC] Above quote is a forward looking statement from the final chapter from "Making a Machine That Sees Like Us" about possible next steps. So we must be a bit cautious.[52] Still it shows an general transition in Pizlo's approach. Pizlo moves away

52 Pizlo's forward looking speculative "idea that might actually work" here only refers to *content-addressable memory of shapes*. His work on symmetry for *shape recovery* is backed by theory, implementation and

from geometric primitives towards the abstract property of geometric symmetry. While Biederman's Geons are *tangible*, Pizlo's symmetries are *intangible*. We will explore a similar way to do building shape classification and retrieval which moves away from geometric primitives towards more abstract features. *Retrival* and *content-addressable memory of shapes* are related topics.

We will return to Pizlo, when we discuss the theoretical role of symmetry in building shape classification in chapter 8.4.

5.4. Architecture Centric

This chapter will investigate approaches to shape classification that originate in architecture and civil engineering and either try to provide a holistic approach or reach over to other science fields to offer compelling options. Discussion about *form* – and therefore about building shape – is present in many architecture publication and architecture theory. Though we will focus on approaches that try to deliver a classification system for shape that can be used together with building collections.

We will start by briefly discussing the difference between *building form* and *building shape*, by looking into architecture *content* and building *context*. We will use publications from Christopher Alexander and his coauthers for this task. By better understanding where *form* starts we can then back up and concentrate on *shape* in more isolation.

We will then discuss two contributions: First there is the publication "IL 22 – Form" (IL 22) by Frei Otto and his team at Stuttgart University (Otto, 1988). The second effort is the research done at the Lightweight Structure Research Unit (LSRU) at the University of New South Wales Sydney in the eighties and nineties. One of the resulting tools of the LSRU is the digital Structural Design Aid (SDA) (Sedlak, 1997) which also contains a *typology of shape* (Loh, 1996). We will focus on "IL 22 – Form" at the beginning of this chapter and return to the LSRU work at the end of this chapter.

5.4.1. Form Contains Content/Context

The first paragraph of this thesis states that it focuses on *building shape* which is *just one aspect of form*. Can we expose the difference between *building shape* and *building form*? Arnheim as well as Alexander argument in a similar fashion that form includes *content*, while shape itself is omitting it. We can use Alexander and his coauthers work to understand what *content* – also refereed to as *context* – is when we discuss buildings.

experimental efforts. (Pizlo, 2008; Pizlo *et al.*, 2014).

Alexander is by no means the only to describe context/content for architecture. Many major works in architecture theory have this as their subject. His systematic approach has some overlap with this thesis and is also very structured, therefore it can serve as one good reference point.

Alexander and his co-authors focus to “describe a way of representing design problems which does make them easier to solve" (Alexander, 1964, p. 6). While the publications are highly interested in a design process that leads to buildings which have *form*, they nearly completely omit any visual forms/shapes. They see the form creation as the task of the designer – the “form-maker” – who is following their proposed design process and try not to interfere. They see an increasing complexity burden on the shoulders of contemporary designers. Their main tool to ease the problem is the *pattern*.

We will inspect three quotes to gather different aspects of a definition for Alexander’s pattern:

- The first definition describes the textual/logical structure of pattern: "Each pattern is a three-part rule, which expresses a relation between a certain context, a problem, and a solution"(Alexander, 1979, p. 247). This is the textual layout of the 253 patterns in (Alexander, Ishikawa and Silverstein, 1977)
- The second quote focus on its logical encapsulation: "The idea of a diagram, or pattern, is very simple. It is an abstract pattern of physical relationships which resolve in a small system of interacting and conflicting forces, and is independent of all other forces, and of all other possible diagrams" (Alexander, 1964, preface of the 1971 edition). While the last phrase suggests a strong independence during their definition phase, patterns do not exist in isolation once they are identified and overlayed with other patterns in a design phase. They can positively interact or negatively conflict and these relationships are the base of the “language” part of “A pattern language”.
- The third quote helps to understand the flexibility given to such a design process, by avoiding being to specific: "Instead, to strike the balance between being too narrow and too loose, you must express and visualise a patterns as a kind of fluid image, a morphological feeling, a swirling intuition about form, which captures the invariant field which is a pattern" (Alexander, 1979, p. 263). This statement justifies the lack of actual illustrations of specific forms/shapes.

While “The timeless way of building” (Alexander, 1979) delivers the theoretical framework, the accompanying “A pattern Language” (Alexander, Ishikawa and Silverstein, 1977) is a repository of 253 predefined patterns including a short usage instruction up front.

By following Alexander we can see that it is possible to discuss building context without discussing shapes directly. We assume that building form starts when we talk about a building and content and context are taken into account. “Only for the sake of extrinsic analysis” (Arnheim, 1974, p. 96) will we try to do the same in the other direction. Discussing shape without discussing context directly. Therefore discussing building shape not building form.[53]

One further overlap exists between Alexander and this thesis; Alexander (1964) tries to introduce a process how *diagrams* – later publications called them *patterns* – can be found. These diagrams can then assist in the creative design process. “The crucial quality of a shape [...], lies in its organization, [...]" (Alexander, 1964, p. 134) Mathematics and Logic are utilized by Alexander to find this *organisation* and he sees these as essential tools to be embraced rather being afraid of (Alexander, 1964, p. 7). While having a common intersection point – the building which has a building form – the *shape organisation* that this thesis is about is quite the opposite direction. This different direction is due to the different objective: Alexander tries to find a system to help design completely new buildings, while this thesis tries to find a system how to classify existing buildings. Though both systems are trying to be computation friendly. Therefore Alexander’s use of Logic has some insights for the accompanying software implementation of this thesis.

5.4.2. IL 22 - Form

Scope

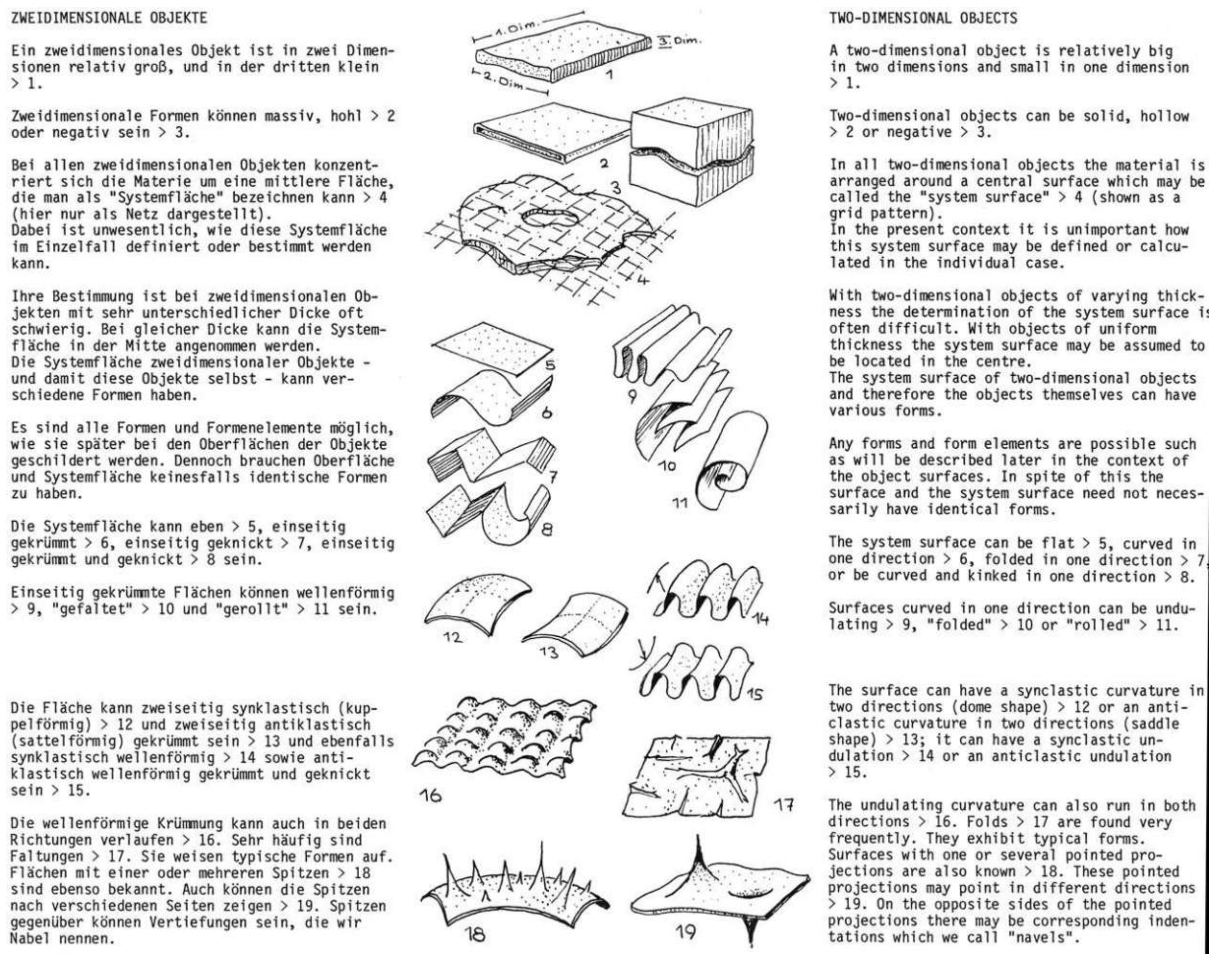
In the previous chapters we looked how cognitive science researchers like Bierderman and Pizlo started to analyse shape. Though even Pizlo’s very recent analytical framework currently covers mostly simple object like chairs. We know that diversity of shapes in the objects that interest us – buidlings – is very broad. We can identify some researchers from the architecture and civil engineering side that also investigated *shape*. Their goal was not to create a computational model, but rather have a classification system and a vocabulary that can accompany their research activities. It is the work of Frei Otto and his team at the “Institut für leichte Flächentragwerke” (IL) and especially the book known as “IL 22 - Form” (Otto, 1988). Due to their background their work is highly visual with a lot of sketches which can transport dense information which is usually hard to describe in text.

The aim of the research institute as a whole is described by its founder Frei Otto as:

> It was never the objective of the IL to create a design theory. Its aim was to find as many abiotic self-forming processes as possible, to simulate them and to understand their implications. Using this method we found many forms, structures and constructions which were not previously known. We discovered that some of the processes we observed are integrated

53 Oddly though the very next headline immediately includes the term “Form”, though this is mainly due to the differences in German and English language and its translation. See also the next footnote.

> by living nature and have an impact on its variety of forms. We also learned to see the major influence they can have on the development of forms in the most varied fields of technology. (Gaß, 1990, Preface)



ZWEIDIMENSIONALE OBJEKTE

Ein zweidimensionales Objekt ist in zwei Dimensionen relativ groß, und in der dritten klein > 1.

Zweidimensionale Formen können massiv, hohl > 2 oder negativ sein > 3.

Bei allen zweidimensionalen Objekten konzentriert sich die Materie um eine mittlere Fläche, die man als "Systemfläche" bezeichnen kann > 4 (hier nur als Netz dargestellt).
Dabei ist unwesentlich, wie diese Systemfläche im Einzelfall definiert oder bestimmt werden kann.

Ihre Bestimmung ist bei zweidimensionalen Objekten mit sehr unterschiedlicher Dicke oft schwierig. Bei gleicher Dicke kann die Systemfläche in der Mitte angenommen werden.
Die Systemfläche zweidimensionaler Objekte - und damit diese Objekte selbst - kann verschiedene Formen haben.

Es sind alle Formen und Formenelemente möglich, wie sie später bei den Oberflächen der Objekte geschildert werden. Dennoch brauchen Oberfläche und Systemfläche keinesfalls identische Formen zu haben.

Die Systemfläche kann eben > 5, einseitig gekrümmt > 6, einseitig geknickt > 7, einseitig gekrümmt und geknickt > 8 sein.

Einseitig gekrümmte Flächen können wellenförmig > 9, "gefaltet" > 10 und "gerollt" > 11 sein.

Die Fläche kann zweiseitig synklastisch (kuppelförmig) > 12 und zweiseitig antiklastisch (sattelförmig) gekrümmt sein > 13 und ebenfalls synklastisch wellenförmig > 14 sowie antiklastisch wellenförmig gekrümmt und geknickt sein > 15.

Die wellenförmige Krümmung kann auch in beiden Richtungen verlaufen > 16. Sehr häufig sind Faltungen > 17. Sie weisen typische Formen auf. Flächen mit einer oder mehreren Spitzen > 18 sind ebenso bekannt. Auch können die Spitzen nach verschiedenen Seiten zeigen > 19. Spitzen gegenüber können Vertiefungen sein, die wir Nabel nennen.

TWO-DIMENSIONAL OBJECTS

A two-dimensional object is relatively big in two dimensions and small in one dimension > 1.

Two-dimensional objects can be solid, hollow > 2 or negative > 3.

In all two-dimensional objects the material is arranged around a central surface which may be called the "system surface" > 4 (shown as a grid pattern).
In the present context it is unimportant how this system surface may be defined or calculated in the individual case.

With two-dimensional objects of varying thickness the determination of the system surface is often difficult. With objects of uniform thickness the system surface may be assumed to be located in the centre.
The system surface of two-dimensional objects and therefore the objects themselves can have various forms.

Any forms and form elements are possible such as will be described later in the context of the object surfaces. In spite of this the surface and the system surface need not necessarily have identical forms.

The system surface can be flat > 5, curved in one direction > 6, folded in one direction > 7, or be curved and kinked in one direction > 8.

Surfaces curved in one direction can be undulating > 9, "folded" > 10 or "rolled" > 11.

The surface can have a synclastic curvature in two directions (dome shape) > 12 or an anticlastic curvature in two directions (saddle shape) > 13; it can have a synclastic undulation > 14 or an anticlastic undulation > 15.

The undulating curvature can also run in both directions > 16. Folds > 17 are found very frequently. They exhibit typical forms. Surfaces with one or several pointed projections are also known > 18. These pointed projections may point in different directions > 19. On the opposite sides of the pointed projections there may be corresponding indentations which we call "navels".

Figure 25: A typical page in "IL 22 - Form" with multiple sketches. The German original text on the left hand side. The English translation on the right hand side. (Otto, 1988)(chapter 1, page 26)

The IL 22 book is part of a series (IL 21 up to IL 25) that documents important research activities of the institute. The institute did a lot of work on lightweight structure, architecture and civil engineering, but the IL 22 publication focuses on a single topic: How to analyse, describe and classify form/shape of objects[54]. It tries to deliver a

54 The IL books are originally written in German and have an English translation on the same page, like visible in Figure 25. In German language, including jargon in architecture, the German word *Form* is used with some ambiguity for both English terms *shape* and *form,* which we distinguish in this thesis. *Form* is the most widely used term and common in architecture. Sometimes German speakers would refer to *Umriss* when they talk about *shape*, but this term is closer to the English term *outline*. Sometimes, but seldom, German speaker would use the term *Gestalt* when they talk about *form.* The term *Gestalt* is heavier and carries more context then just *Form*. The Gestalt psychology movement (see chapter 5.3) made the German term known in the English language. In English *Gestalt* is mostly associated with the *Gestalt Movement*, while the German use of the word is broader.

The challenges to translate from German to English can be observed in the following German sentence:

> Neben dem Begriff Form wird häufig der Begriff "Gestalt" verwendet. Er ist in seiner Bedeutung weitgehend vermieden, außer wenn auf das Produkt eines künstlerischen oder biologischen Schöpfungsprozesses hingewiesen werden soll. (Otto, 1988, p. 68)

And its English translation :

framework that suits any kind of object that exists in the real world and has a mass and material, not necessary limited to a certain application like architecture.

The scope of IL 22 is defined as:

> We arrived at the conclusion that a method of classification had to be looked for which applies without exception to all objects, i.e. which is itself so comprehensive and 'imprecise' that it can encompass all forms, whilst at the same time being detailed enough that any form may without exception be categorized and described with sufficient accuracy (Otto, 1988, p. 70)

IL 22 deliberately omits *theoretical* objects like geometries that only exist in an artificial mathematical world. Geometrical objects might have no mass and a surface thickness of zero, while real world objects can appear linear or planar and be very thin in some dimensions but still have a mass and surface area. Real world object might be perceived as one-dimensional or two-dimensional but are actually always three-dimensional.

Objectiveness / Cognition

Even though the book was written by architects and civil engineers, they pretty early came to the same conclusion as cognitive science researchers. It is challenging to have real objectiveness when doing shape classification. As the judgement by a human will be influenced by genetics and the environment[55].

Their goal is the following:

> The most accurate description of a form is that which causes even unknown (completely new) forms to be registered by the mind and familiar forms to be recognized (Otto, 1988, p. 14).

We can recognize a parallel theme to generative linguistics which tries to understand an infinite amount of sentences, which one might have never heard before, with a finite set of elements and rules. The same pattern was also present with Biederman Geons. So the IL 22 team looked for a system which cognitive scientist would describe as *generative*.

They point out that "With simple objects a geometrical description is possible; with objects of complicated shape this sort of description becomes extremely difficult" and

---

> Apart from the term "form" the term "shape" is often used. The later has been largely avoided except when pointing at the product of an artistic or biological creative process. (Otto, 1988, p. 68)

We can see that there is a mismatch in the use of "Gestalt" and "shape" in the original and the translation. Merriam-Webster (Online accessed 2017) defines *shape* as "the visible makeup characteristic of a particular item or kind of item" and *form* as "the shape and structure of something as distinguished from its material". So *shape* is the lower primitive and *form* the one with more context. This is the hierarchy used in this thesis and consistent with the definition of Arnheim in chapter 1.2.

55 Cognitive science sees shape recognition as an internal capacity of the human mind.

then they propose that "A comprehensive (and largely objective) description comprises a comparison, a qualitative and quantitative analysis as well as the weighting of possible subjectiveness." (Otto, 1988, p. 14). The terms quantitative and qualitative are used in similar fashion like in Vision research. So quantitative refers to the metrical description, while qualitative refers to properties or features. And in fact the central chapters of the publication focus mostly on qualitative features and at *parts and elements*[56].

Dimension First; Surface Second

This section will give only a brief enumeration of some of the qualitative property sets from IL 22 and how they are connected. The importance of qualitative properties is a conclusion that this research will also follow in this thesis. Therefore more detailed comparisons will be included later in context. We will see an overlap of IL 22 terminology and the proposed classification sets.

According to the IL 22 authors the form of an object is above all characterised by its proportions. The primary items within proportions are:

- (predominantly) one-dimensional. E.g. bars, pipes, threads.
  The authors also point out that the ends of such objects might have a different shape. E.g. a sharp tip, a rounded tip, or a complex three dimensional shape.
- (predominantly) two-dimensional. E.g. paper sheets, shells, soap skins.
  Similar the authors point out that the edges of such objects can have distinct characteristics by themself.
- (predominantly) three-dimensional.

Three dimensional shapes are characterized by the absence of a dominating small or large dimension. Therefore they are less defined by proportions and more by their *surfaces*[57]. The objects that we will investigate in this thesis are World Exposition pavilions and following above definition they are all three dimensional. So the surface properties become of special interest for us.

Surfaces can have the following properties:

- “Form of a surface” – E.g. flat, curved in one direction, convex, concave, folded in one direction, or be curved and kinked in one direction.
- “Structure of a surface” – E.g. flat like a mirror, undulated, covered with fur or feathers. So the structure itself can have an own shape but is usually at a different

56 One of the main chapters is headlined “Erfassbarkeit”/”Perception”. IL 22 also contains chapters about “dynamic and variable forms”, as well as a “worlds of forms” which we will not take into account here.

57 The original German text points this out clearly: "Sie [die Oberfläche "O"] vor allem bestimmt die Form jedes Objektes" while unfortunately the English translation has flipped the statement around "The surface is above all determined by the shape of the object"(Otto, 1988, p. 17)

scale. Because the term "structure" is often used in this thesis we will later call this concept "texture".

- High points and low points - The tip of such a point might itself have a different shape.
- Ridges and Valleys – They might consist of a single linear members or split up similar to mountain ridges and river valley.
- Corners – E.g. From the seldom corner with only one edge and one surface, to the very common corner with three edges and three surfaces.

The IL 22 team points out that usually we can distinguish more then one surface on a three dimensional object because the edges / ridges / valleys are separating identifiable surfaces. For instance a cube is commonly considered to consist of six surfaces. But it is also possible to have three dimensional objects to consist of a single surface, like for instance a sphere. The sphere is by far not the only such imaginable objects, as a surface might have local high point, ridges and corners, like visualised in Figure 26.

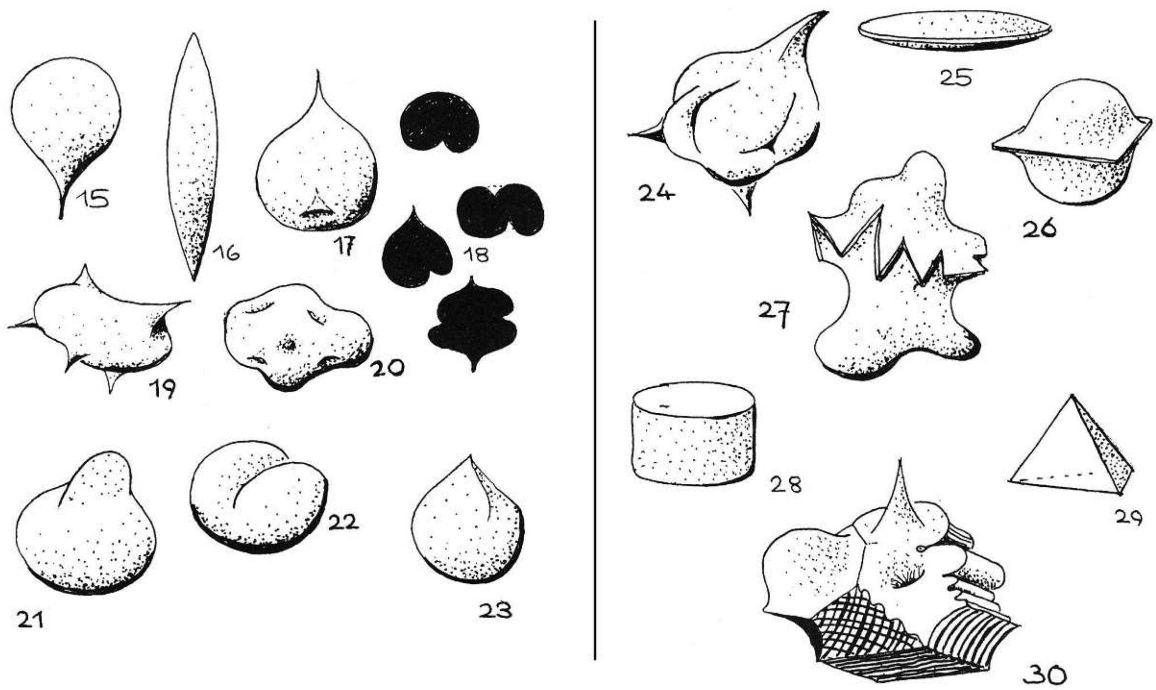


Figure 26: Left: Three dimensional object that consist of only one identifiable surface but can be further identified by features like, high points, low points, ridges and valleys. Right: Three dimensional objects with two (25, 26, 27), three (28), four (29) and many (30) surfaces (Otto, 1988)(chapter 1, page 43)

Parts and Elements

The IL 22 team states that it is not uncommon that objects are composed of more then one element. They provide a pattern how we can distinguish these kind of compositions. The pattern is build upon the definitions of one dimensional, two dimensional and three dimensional forms from their earlier chapters.

- Composite Objects – Are composed of things that have roughly the same scale. The whole is called “object” and it is made up by “parts”[58]. E.g. A hammer head and a handle.
- Small Elements – When an object consist of a large number of components that are *in all relevant dimension* at a significant smaller scale, these are called “small elements”. E.g. bricks that make up a wall.
- Large elements – When an object consist of a large number of components that are in *at least one relevant dimension* at the same scale like the object, then these are called “large elements”. E.g pages in a book.

The book does not provide any rules or vocabulary for the arrangement of parts, small elements or large elements. Its main function is to determine how many dimensions the resulting whole object will have.

Even though the technical term *recursion*[59] is not mentioned in IL 22, it is implicit at multiple places. For instance it is mentioned that the tip of a one dimensional shape can have a different, even three dimensional shape, by itself. The same is true for the edge of a two dimensional surface. Surfaces can have structure / texture like undulation, shed, fur or feathers that can have shape by itself. Also in the *parts and elements* chapter it is mentioned that each thing that might be a small element in one set up might very well be the object at a different scale level. For instance when we look at a feather and start zooming in. As we learned in earlier chapters, *recursion* is a typical *generative* characteristic that linguists are so interested in. The same kind of recursion also appears in Marr and Nishihara with the zoom of the body, to the arm, to the hand, to the finger in Figure 14.

5.4.3. Structural Design Aid (SDA)

The research team of the Lightweight Structure Research Unit (LSRU) at the University of New South Wales Sydney had academic ties with the team from University Stuttgart. Though on their project *Structural Design Aid (SDA) (Sedlak, 1996)* they had a far more focused and applied scope:

> The key aim of the SDA is to provide architects, engineers, students and other designers with an interactive tool during the conceptual design stage. This allows design solutions to be established interactively, promotes valid decision making concerning structural system choice and facilitates assessing the impact of these choices on the building design. (Sedlak, 1997)[60]

58 The German original text is a bit more consistent and always refers to “Teile”/“parts”, while the English translation sometimes refers to “parts” and sometimes “components”.

59 For *Recursion* see Glossary chapter 2 and chapter 8.1.,

"Structural system choice" is central to the SDA. Information about structural types like frames, trusses and tensile structures constitutes a significant portion of the SDA. Information about lightweight structures is more versatile compared to other types. Structural systems are given more attention then shapes. Still shape is treated as a distinguished concept with its own classification tables and catalogues. The overlap of "form active" structures and shapes is one of the threads that connects both topics.

By defining its main audience as people who participate in architecture, civil engineering and related built environment sciences and practice the SDA can assume some pre-existing knowledge that it can build upon. The audience is also assumed to be in a "conceptual design stage", so it can be assumed that construction of new buildings is the anticipate goal.

This has a significant implication on the *typology of shape* (Loh, 1996) which is the foundation for the shape related database tables in SDA. Loh makes a distinction between *form* and *shape*. This distinction is similar to the one employed in this thesis which follows (Arnheim, 1974) as discussed in chapter 1.2. But while this thesis pursues the path of what Arnheim calls the *perceived shape*, Loh is utilising the other available option: *physical shape*.

> To perceive form and space, shape is crucial aspect. It is the physical manifestation of form and space. Shape is the physical entity to which both man and environment relate and respond instinctively and immediately. Shape is the presence, the tangible.(Loh, 1996)

Similar to this thesis, Loh also narrows down the subject to *building shape*. A further split is done to differentiate between *building volume shape* and *structure shape*. We will focus on *building volume shape* as it is closer to the building shape definition of this thesis.

The proposed typology starts of with geometric primitives and applies transformations to them, similar to the workflow in a 3D modelling software package. Geometry is one of the driving forces in the proposed classification. This can be seen as an interdisciplinary move from the SDA. Geometry is part of mathematics but it allows to create three dimensional objects in an abstract planing phase and then helps the realisation of such designs in the real world. In the construction phase geometry helps with its precision to

60 The original database which the SDA was based on had a broader theoretical scope. One focus area was the relationships between use, shape and structure.

> It's principal aim was to provide a basic theory for the understanding of (lightweight) structures and their application in architecture and building.
>
> The project attempted to establish the relationship between use, shape and structure type of lightweight structures. Based on the hypothesis that there exists a logical grammar which rules these relationships, and once established, it can be used as a predictive design tool [...]
>
> The outcome from this research did not show clear associations between the target categories (use, shape and structure), however associations between sub-categories of these primary categories were demonstrated. (Sedlak, 1997)

transfer architecture designs into models that for instance can be used by civil engineers to calculate the load bearing forces that are in effect in the real world.

The main shape typology of SDA consists of eight solid geometrical bodies. They are called the *primary shape units*. These eight shapes are grouped into two groups:

Directional shapes:

- Prisms
- Cylinders
- Vaults

Concentric shapes:

- Polyhedra
- Pyramids
- Cones
- Spheres
- Domes

We can observe that two members are not the typical geometrical primitives: vaults and domes are included. Even though one can argue that vaults might be a special kind of truncated horizontal cylinder, this is a to limited point of view. A vault can for instance also be constructed based on the extrusion[61] of a hyperbola, parabola, or even a catenary curve[62]. The same is true for a dome. A dome might be a truncated sphere but can also be constructed by rotational symmetry of a hyperbola. Use of these kind of curves can result in form-active structures that have optimized structural characteristics. Though vaults and domes can also be constructed from less optimized free form curves or from faceted curves that consist of straight subelements[63].

Loh lifts vaults and domes to first class citizens in her typology because her subject is *building shape*, rather then shape in general. In the real physical world gravity exists, and designers often want to enclose usable ground plane area with little physical material. Optimised use of physical resources like steel and concrete might for instance be driven

61 *Extrusion* can also be seen as a *translational symmetry* operation

62 A *catenary curve* can be described by a mathematical formula, but it origin is the real world. The driving force of the curve is earth gravity and weight of the curve itself. Some well known examples of the use catenary models can be found in the works of Antoni Gaudi.

63 The *typology of shape* enumerates various special kind of vaults which are present in buildings: Semicircular, Segmicircular, Hyperbolic, Parabolic, Pointed, Conoid, Rampant, Conical, Rising, Horseshoe, Ogee, Tudor and Trefoil. The enumeration for Domes consists of: Spherical, Hemispherical, Calotte, Ovoid, Spheroid and Semi-ellipsoid

by financial constraints or the anticipation to consume less of a limited natural resource so the environmental impact is reduced[64].

The eight primary shape units form the foundation of this typology of shape. Each of this primary shape unit can be transformed given a set of attributes. The result of such a modification or transformation is a *secondary shape unit*.

Common attributes that are proposed for all primary shape units are: Oblique, Raked, Truncated, Curved, Concave, Convex, Synclastic, Saddle, Inverted, Inclined, Ridged, Navel, Polyhedral, Horizontal, Vertical. Each of these attributes is provided with a brief description. Some of these attributes form smaller logical groups; for instance Concave and Convex. Though these sets are not strictly defined at the common level.

Each of the primary shape units defines its own set of valid attributes. It reuses most, but not necessary all, common attributes from the previous paragraph. For each primary shape unit the logical groups are defined but are given now semantic name. For instance the primary shape unit of a *cone* has:

- “Primary Shape”: (Circular), Triangular, Square, Rectangular, Pentagonal, Hexagonal, Octagonal, Polygonal, 3-sided, 4-sided, 5-sided, 6-sided, 7-sided, 9-sided, 11-sided, 14-sided, etc.
- “Attribute 1”: scallop, umbrella
- “Attribute 2”: ridged
- “Attribute 3”: (right), oblique, raked, truncated
- “Attribute 4”: saddle, synclastic
- “Attribute 5”: inverted, inclined

We see the term “Primary Shape” as the first enumeration in each primary shape unit. It seems to be reserved for the attributes that influences the shape the most. Default values are given in parenthesis like “(Circular)” or “(right)”. Though what might be the “primary shape” attribute for cone, pyramid and prism, is only “Attribute 1” for the dome and is not present with cylinders. The use of anonymous names like “Attribute 1” for the groups is most likely due to technical limitation of the database software that was used for this version of the SDA.[65]

64 Some proponents – like the IL team – who are involved in light weight structures claim that a certain *quality* can be achieved and will drive *aesthetic perception* when buildings use natural resources in a smart way (Schaur, 1979)

65 It was maintained on a table based desktop database software with little relational database technology features available out of the box. The use of these anonymous column names allowed a more compact data layout. It was identified by the team that some anticipated database queries have been made harder by this technical choice and a composite column was added that concatenates the values from the anonymous columns. Many database queries require some data consistency to be useful as filters and data constraints.

The typology of shape also provides a system how to express the presence of multiple shapes in a single building: It is called *Arrangement* and consist of three layers. When several of the aforementioned primary and second shape units are combined they form *shape aggregates*. When several shape aggregates are combined they from *shape composites*. Six primary arrangements are identified:

- Sequential – basic linear arrangement – parallel to the axis of the units / aggregates that are arranged
- Parallel - basic linear arrangement – similar to Sequential but the arranged units /aggregates are side by side
- Radial – multiple linear arrangements meeting at a common centre
- Two-way – a combination of Sequential and Parallel in two dimensions
- Three-way – the development of Two-way arrangement in a further dimension
- Peripheral – A special case where the units / aggregates are arranged around a closed boundary line.

Each arrangement contains a description and often a dictionary definition to prevent ambiguity. There is a certain hierarchy within the items: Sequential and Parallel are the basic blocks which the other four are building upon. Each primary arrangement can be combined with “numerous” attributes. Some commonly used attributes are enumerated: horizontal, vertical, back to back, diagonal, orthogonal, offset, overlapped, close-packed and unequal. This allows the description of more complex arrangements. Some example combinations of primary arrangement plus one attribute are provided to show the reader the anticipated pattern.

[BSC] We will see similar terms in the *Spacing* and *Orientation* classification sets in chapter 6.6.3 of this thesis. The arrangement work of Loh is an influence on this thesis and preliminary work by the author (Jurewicz, 2005) tries to further structure and evolve the arrangement items. Jurewicz (2005), also enhance the arrangement vocabulary by splitting up *Spacing* and *Axis*. It also further tries to formalise orientation and cardinality.

The typology of shape also identifies the four well known types of symmetry: bilateral, translation, dilatation, rotation. Symmetry forms a separate attribute group. It applies only to arrangement and not to primary/secondary shape units.

[BSC] Symmetry has a certain hidden complexity on which for instance Pizlo elaborates on (see chapter 4.1). This thesis also investigated symmetry and identified it as something that can occur in arrangement as well as the smaller unit called

Periphrase. Symmetry can be identified even further down on many classification item themselves (see chapter 8.4). In the first software implementation for this thesis symmetry was omitted because it can occur at so many levels with various degrees of importance to the identity of a shape. It adds significant complexity to the software implementation itself. Therefore it is understandable that the *typology of shape* does also use it only in the arrangement part.

The 1997 version of the SDA tries to connect the shape typology, shape catalogues and building collection with a *Mnemonic Code*.[66] It is a kind of short notation which is still human readable but tries to capture all the attributes in a text fragment. Figure 27 up to Figure 41 show sketches from the SDA and examples of the Mnemonic Code.

[BSC] Unfortunately there is no strict syntax definition of the mnemonic code accessible[67]. Though by inspecting its use in the shape catalogue and building collection of SDA some conclusions can be drawn: Even though it is a very compact notation, the mnemonic code is closer to the freedom of text then to a strict technical syntax that is constraint by binary rules. Some flexibility is applied to describe complex buildings. This leads to ambiguity which is hard to manage for a software parser. The mnemonic code was parsed by humans that worked on the SDA as a textual short notation. As seen in the chapters about linguistics (5.1), humans are very capable to close the gaps and solve ambiguity by utilising more *context*, like in *pragmatics*. This thesis tries to introduce a data structure for building arrangement that is understandable by humans and parseable by a software which is called *Building Shape Syntax Tree*.

The SDA does not only contains structure and shape typology tables but also a comprehensive collection of 467 real world buildings. This building collection contains 88 vaults and 80 domes.

66 The 2001 version of the SDA additionally adds relationships between building collection and shape catalogue with relational database technology. This work was done by the author of this thesis.

67 It might be part of "A vocabulary of shape and structure type in Australian applications of lightweight structures" (Loh, 1989). And be a building block for the attempt to find a grammar for lightweight structures in this research effort. This PhD thesis is available at the UNSW Sydney main library.

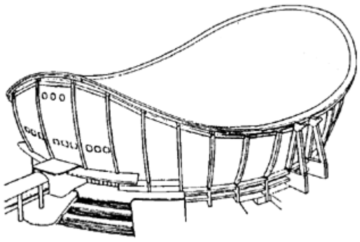


Figure 27: SDA building S 552
“Olympic Dome Calgary”
with single unit building shape
“Cylinder vert: saddle top”

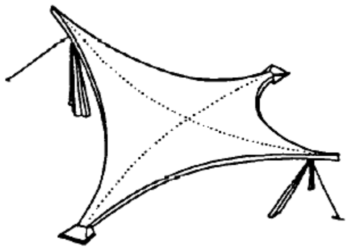


Figure 28: SDA building E 559 T
“Pavilion Euroflor Dortmund”
with single unit building shape
“Prism saddle o/s”

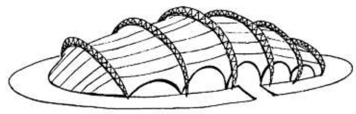


Figure 29: SDA building J 509
“Chemical Research Centre Venafro”
with single unit building shape
“Dome calotte: ellipse: saddle* 6 arch seq: horiz”

A cautious disclaimer: The human parsing and interpretation of all Mnemonic Code in the following bullet points is a best effort attempt of the author of this thesis, and does not originate from SDA.

Notes about building that consist of a single modified shape unit:

- Figure 27 - S 552 - “Cylinder vert: saddle top” - We see “Cylinder” as the shape family; “vert” for the vertical orientation of the cylinder; “:” as a delimiter; “saddle” as a description of the roof; “top” as an indicator that “saddle” is describing the top / roof.
- Figure 28 - E 559 T - “Prism saddle o/s” - We see “Prism” as the shape family; “saddle” as a description of the roof; “o/s” as an abbreviation of open sides. The SDA would see an ideal vertical plane connecting the roof edge and the ground. Due to this vertical plane, this building is associated with the prism family.
- Figure 29 - J 509 - “Dome calotte: ellipse: saddle* 6 arch seq: horiz” - We see “Dome” as the shape family; “calotte” because the dome is less than a hemispheric dome; “ellipse” refers to the ground plane; “saddle” is referring to the roof parts; “*” is an indicator that there are multiple saddles present; “6” is the actual cardinality; “arch” is referring to the well visible arches; “seq:” is the arrangement of the saddles/arches; “horiz” is the orientation of the arrangement[68]

68 Especially for J 509 “Chemical Research Centre Venafro” example building. As mentioned above: This parsing is a best effort attempt. The classification system introduced in this thesis would also struggle with a clean classification of a complex building shape like this. The SDA is not sure either. The classification as a “Dome” looks at the whole building as a single unit. While a drill down exposes the six saddle surfaces and the five arches. This is described in the arrangement notation. The arches would suggest that this is a vault shape.

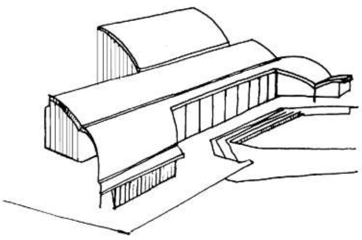


Figure 30: SDA building E 29 "National Maritime Museum Sydney" with aggregate building shape "Vault segmi*4/parall:dilat"

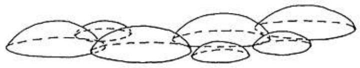


Figure 31: SDA building R 04 "Kallangur Shopping Centre Brisbane" with aggregate building shape "Dome calotte4 dome calotte3*7/seq offs"

Figure 32: SDA building V 02 "Centrepoin Tower Sydney" with aggregate building shape "Cylinder:vert*2/seq:vert cone trunc top"

Notes about buildings that contain an arrangement of multiple shape units:

- Figure 30 - E 29 - "Vault segmi*4/parall:dilat" - We see "Vault" as the shape family; "segmi" is an abbreviation for Segmicircular[69]; "*" indicator that multiple vaults are present; "4" the actual cardinality; "/" the beginning of the arrangement; "parall" parallel arrangement; "dilat" dilatation symmetry, because the size of each vault continues to change in size.
- Figure 31 - R 04 - "Dome calotte4 dome calotte3*7/seq offs" - We see "Dome" as the shape family; "Dome calotte4" points to the four bigger domes; "dome calotte3" to the three smaller domes; "*" indicator that multiple domes are present; "7" the actual cardinality; "/" the beginning of the arrangement; "seq" sequential arrangement; "offs" offset because some of the individual units do not align exactly on one axis
- Figure 32 - V 02 - "Cylinder:vert*2/seq:vert cone trunc top" - We see "Cylinder" as the shape family[70]; "vert" is the vertical orientation of the cylinders; "*" indicator that multiple domes are present; "2" the actual cardinality; "/" the beginning of the arrangement; "seq" sequential arrangement; "vert" as the orientation of the arrangement axis; "cone trunc top"[71] refers to the unit above the cylinders and below the spike.

69 Definition:

> Segmicircular vault- 'Segmicircular' is coined from two words: segmental and circular. A segmicircular vault is a vault with a cross section of a segmicircle and therefore, shallower than a semicircular vault. The line joining the two ends of the segment is a chord.(Loh, 1996)

70 Please be aware that there is a tender hyperbolic cable structure present, which is a bit dominant on the SDA sketch. The hyperbolic cable structure is covered in structure parts of the SDA. The building volume shape concentrated on the enclose solid cylinder.

71 There is no punctuation indicator before "cone trunc top" (or it might got lost in some data conversion) to indicate that the arrangement information is finished. It seems it is starting again to describe a modified shape unit. Also no information how the cylinders and cone are arranged is present. This is challenging for a software parser. A similar problem is also present in R 04 - "Dome calotte4 dome calotte3*7 [...]". R 04 is also missing information about the relative size between calotte4 and calotte3

In between the strict typology and the collection of real world buildings the SDA positions a *shape catalogue* with 275 entries.

On the one hand it connects the typology to the collection as the shape catalogue provides many derivations that are present in the real world. Because most real world projects are not as pure as the choices from the typology.

On the other hand the shape catalogue also tries to cater the "conceptual design stage" of its users and tries to introduce shapes which are less common. This can for instance be observed in the 80 Platonic and Archimedian solids that are included[72]. Also the derivations of tensile structures goes beyond the building collections and depicts some theoretical buildings.

Figure 33: SDA shape CO 14
"Raked Anticlastic Cone"
with modified unit shape
"cone:circular:anticlastic:raked"

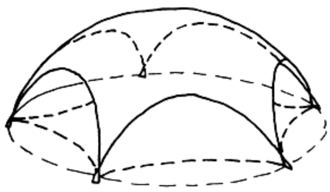


Figure 34: SDA shape DO 07
"Scalloped Calotte"
with modified unit shape
"dome:calotte:5-sided:scalloped"

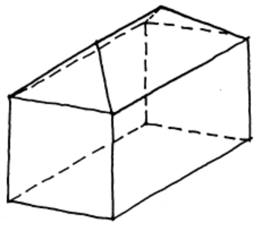


Figure 35: SDA shape PR 15
"Hipped Prism"
with modified unit shape
"prism:rectangular:horizontal:hippe
d-top"

Notes about some *unit* attributes in the shape catalogue:

- Figure 33 - CO 14 - "cone:circular:anticlastic:raked" - ... "raked" truncation of the tip of the cone.
- Figure 34 - DO 07 - "dome:calotte:5-sided:scalloped" - ... " scalloped" truncation of the base of the dome.
- Figure 35 - PR 15 - "prism:rectangular:horizontal:hipped-top" - ... " hipped-top" the SDA classifies these kind of houses primary as prisms because of the vertical walls. The roof geometry is a secondary attribute only and not a independent shape unit.

72 Platonic and Archimedian solids have also the arrangement property of *close packing*. This is well visualised in "Order in Sapce" (Critchlow, 1969) and picked up by (Loh, 1996) and documented as a hierarchy in (Jurewicz, 2005). Close packing, especially the three dimensional versions, is an intriguing geometric property but is omitted in this thesis because nearly none of the examined World Exposition pavilions utilised it.

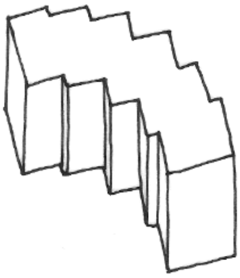


Figure 36: SDA shape PR 62 "Aggregate Prism" with aggregate shape "prism:rectangular:vertical*5/sequential:curved"

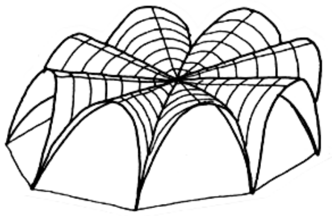


Figure 37: SDA shape VA 20 "Crossed Vault" with aggregate shape "vault:parabolic*4/radial"

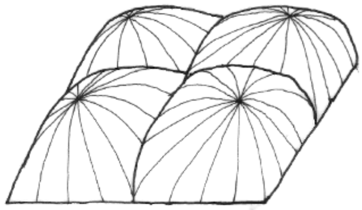


Figure 38: SDA shape DO 32 "Dome Aggregate" with aggregate shape "dome:square*4/2-way"

Notes about *arrangement* attributes in the shape catalogue:

- Figure 36 - PR 62 - "prism:rectangular:vertical*5/sequential:curved" - ... "/" the beginning of the arrangement; "sequential" arrangement; "curved" is a qualifier of the axis.
- Figure 37 - VA 20 - "vault:parabolic*4/radial" - ... "/" the beginning of the arrangement; "radial" arrangement.
- Figure 38 - DO 32 - "dome:square*4/2-way" - ... "/" the beginning of the arrangement; "2-way" arrangement.

5.5. Reflections on Interdisciplinary Input

The dive into cognitive science from an architecture and civil engineering point of view was valuable, inspiring and very surprising. The smaller insights and tangible *lesson learned* are inline right in between the summary paragraphs[73] from the other domains. This chapter provides some higher level reflection on the interdisciplinary input. The interdisciplinary overview presented before must be taken cautiously. The disciplines of Architecture and Civil Engineering on the one side and Linguistics, Vision, and Music Theory on the other side are quite far apart. It might very well be that the author has missed an important fact. It is a selective point of view with some cherry picking. This is done with the best intention and as thorough as the scope allowed it.

Different Speeds

One thing that become quickly apparent are the different speeds at which different domains are performing digitalisation of their connected data. Linguistics has with *text* a common data format that can be digitalized, parsed and analysed in incredible

73 The paragraphs are marked with a prefixed "[BSC]"

quantities. One impressive example is an academic reply to Noam Chomsky by Google head researcher Peter Norvig. Norvig (2017) writes that he just “repeated the experiment [...] over the Google Book Corpus from 1800 to 1954”.

It should be noted that architecture / AEC is not an analogue art form and is not totally legging behind. The amount of digital data that is created for the construction of a single bigger building project is enormous. Still linguistics is able to connect their data across case studies (e.g. books), while this is much harder for buildings[74].

But the quantity of material like *text* or *3D data* is not necessary a measure of success. Most of the work that we have looked into are actually *theories* that want to create insights and understanding. In Vision research starting with Marr and also in the linguistic work of Jackendoff there is a trend that a working computational implementation of a theory is the “gold standard”. We saw that *recursive binary tree* structures are introduced as novel data model within the domains. From a computer science point of view a *recursive binary tree* is not news, but a pattern solved long ago. Also the three layers introduced by Marr or the parallel data structures from Jackendoff are not really computer sciences challenges, but typical software development tasks. The possible value of contributions like the one that will follow in the next chapters are not computer science innovations but rather the computational model for a specific domain. With a “domain” so narrowly scoped like “just building shape of World Exposition pavilions” it is possible to see the theory, the computational model, the implementation and the empirical reference system in one doctoral thesis.

Chomsky’s Syntactic Structures

Reading Chomsky’s Standard Theory original text partly (Chomsky, 1957) and his quite accessible Berkeley Lectures held in 1967 in German translation (Chomsky, 1980) was an essential trigger to start this thesis. The amount of research that was initiated by his contributions is impressive.[75]

74 Vision research is somewhere in the middle. Vision research is currently in a new digitalisation phase. Due to advances in digital photography – think Google Street View – there is a huge amount of visual information available. Though the information is based on pixels and not CAD construction data.

75 First personal footnote: The personal anecdote leading to investigate Chomsky and therefore starting this thesis began with Michel Foucault. There was a need to better understand where (Jurewicz, 2005) could be improved. There were difficulties to do classification and comparison with some ordinary building shapes. Technically the research was based on the Web Ontology Language (OWL) (see Glossary chapter 2) which is part of the Semantic Web. OWL is used for classification and logic. A read of Michel Foucault “Die Ordnung der Dinge” / ”The order of things” / ”Les mots et les choses” (Foucault, 1974) was supposed to bring a new point of view about classification; the system behind the system. Foucault discusses classification in chapter 5 and the following chapters build upon it. But the book also picks Language and Economy as a second and third theme. Ending with a chapter about Life Sciences. This thread lead to an TV interview “ (*Debate Noam Chomsky & Michel Foucault - On human nature [Subtitled]*, 1971). The debate can be found on Youtube https://www.youtube.com/watch?v=3wfNl2L0Gf8 . An academic transcript with additional information is also available (Chomsky and Foucault, 2006). In this debate a young Noam Chomsky stresses the importance of the innate capacities of the human brain, and describes it with the

Chomsky also introduced two successor theories: Government Binding Theory 1981 and Minimalist Program 1990. Trying to read these original publications proved to be very challenging for an external person. The books are written for an audience that is well aware of decades of linguistic research. It required secondary literature. The personally most accessible overview was written from a non-linguist in a philosophical context. Bidese (2002) is giving an overview of the evolution from "Syntactic Structures" that leads up to "Minimalist Program". A further secondary source was a linguistics text book (Isac, 2008).

The definition of *Deep Structure* in (Chomsky, 1957) was the original introduction of binary trees notation in linguistics. The *Deep Structure* of the original *Standard Theory* was mostly eradicated in Chomsky's *Minimalist Program* 33 years later[76]. Still the recursive binary tree operations are present in the *Minimalist Program*. The fact that (binary) tree structures are present in all three Chomsky theories as well as many competing theories (Hacken, 2007) seems to be be a good indicator that they have certain qualities that might be useful in other domains as well.

Cognitive Jackendoff and Interdisciplinary Jackendoff

Following the thoughts of linguist Jackendoff was inspiring. He points out at multiple occasions that he sees the same characteristics appearing in various disciplines within cognitive science. For instance in linguistics, vision, music and complex-task-planning. He also offers a theory how to connect many of them with *interface rules*, and his theory is open for extension. In his work with Lerdahl on Music he showed how to connect a different domain in a flexible way. They found out early that trying to force strict syntax structures from linguistics to other domains is to problematic. They rather transferred

linguistic research he conducted. Chomsky's overall academic and political fame did surely also influenced the decision to further investigate his approach.

76 Second personal footnote: Finding out that Chomsky himself dropped Deep Structure was somehow disappointing at first encounter. It provided an elegant solution which seemed fitting for the building shape problems. It felt like a historic dead end. Further reading into Generative Grammar linguistics was suspended. Again a look into Logic seems to be the more promising path. This lead into a reading of the foundational 1922 "Tractatus logico-philosophicus" from Wittgenstein (Wittgenstein, Russell and Ogden, 2007). The text is famous for its ridged text structure and ends with the famous quote "Whereof one cannot speak, thereof one must be silent." („Wovon man nicht sprechen kann, darüber muss man schweigen."). This lead to a partial read of Wittgenstein's second major work which contains the "Language Games" (Wittgenstein *et al.*, 1953). One might argue that Language Games are written in a behaviourist/externalist tradition. Reading it after being exposed to information about the cognitive revolution that Chomsky was part of was revealing. Some of the assumptions in the Language Games from Wittgenstein can be immediately challenged by Chomsky's concepts. For instance Internal I-Language vs External E-Language. Then the Innate Capacity for language that is present in every child which is acquiring one or even many languages. As well as the Generative Grammar that can produce all the different sentences that people understand and still make them accessible to analysis. This again shifted the research back to Linguistics. In the process to better understand where contemporary Linguistics put structures similar to Chomsky's original Deep Structure the work from Ray Jackendoff was found. Jackendoff's interdisciplinary work as well as his ability as a writer to describe his concepts in an accessible way for external readers proved to be personally pivotal.

the general thought model and techniques. This cautious approach helped in this doctoral thesis as first early attempts also tried to apply the hierarchical linguistic model in a to strict fashion.

The prolongational reductions of music like in Figure 13 showed how to reduce a complex item. Music is not parsed into binary true or false statements but rather interpreted and enjoyed by the listener. So the reductions try to capture the essence rather then aggregate in a mathematical way. In their empirical work Lerdahl and Jackendoff played the reduced samples to a test audience. The audience was asked which reduced sample they "prefer" to be closer to the original piece of music.

Reduced data is easier to handle, therefore it is easier to write software that compares two of these data structures with each other. The ability to compare building shape by a software is an import enabler that allows to verify the theory with empirical data. See chapter 9.

The use of four different notations to describe the same piece of music also helped this doctoral thesis to introduce Building Shape Periphrase in addition to Building Shape Syntax trees. Early attempts in this thesis tried to encode all shape information into binary trees, which lead to unnecessary complexity.

Vision ... at Flux

It was surprising to find that the discipline of Vision was so competitive within itself. The discipline is at flux and some "unconscious strategies for filling in the unknown information" are still at place. Biederman's Geons approach was insightful, because it came close to the building shape task. Though after more then twenty years Geons are not considered successful due to the lack of a working implementation. Which side in Vision research is right or wrong for its big picture is something that I – as an external visitor – am by no means able to judge. Though it was fascinating to follow Pizlo's argumentation that has a very disruptive nature. We will see *cherry picking* later in this thesis from many Vision researchers when we try to argue why a certain architecture feature can be described or framed in a certain way.

We are doing things in architecture research that we take for granted: like the influence of gravity, symmetry, or looking at 2D photographs of buildings. It was reassuring to find that some of these gut feelings can actually be backed by empirical Vision research.

Gestalt and Marr

It was surprising that two terms reappeared over and over again:

- *Gestalt psychology* as a historical origin

- *David Marr* for his conceptual layered approach[77]

This has two positive reassuring influences on this thesis:

- The decision to go with Arnheim's *perceived shape* rather then the *physical shape* seems well supported.
- The decision to look for a computational structure and an implementation seems the right way forward.

Recursion

Recursion "in which the solution to each problem depends on the solutions to smaller instances of the same problem"(Graham *et al.*, 1994). Within linguistics there is a debate about the role of *recursion,* especially in syntax. Chomsky and colleagues even argue that *syntactic recursions* is what makes the human mind unique and differentiate us from animals. While Jackendoff is a bit more cautious (Pinker and Jackendoff, 2005). But no side of the argument questions that recursion is important. In Vision (Marr and Nishihara, 1978) recursion is also applied to dive deeper and deeper into shape detail: from body, to arm, to hand, down to a finger like in Figure 14. In computer science and software development, recursion is a day to day pattern and technically well understood.

Together with the binary tree data structure, we will see recursion be the backbone of Building Shape Syntax Trees in chapters 8 and 9.

Qualitative versus Quantitative

In Vision research some prominent researchers stress that humans are unreliable at quantitative properties. These are things like metric values, aspect ratio and angles. But humans seem to perform better on qualitative properties. These are for instance direction of curvature, contour lines and high points. The quantitative properties are of course essential for the construction process of a building and they dominate the engineering side of architecture and civil engineering. But buildings do not exist to be constructed but rather be used throughout many years. Therefore most of the time a building and its building shape is *perceived*. Our definition of building shape is already based on Arnheim's *perceived shape*. When Vision research suggests that qualitative properties work better, this will have an impact on the building shape classification sets. At the beginning of this research the classifications sets were mostly *quantitative* and based

77 This might very well be a coincident and be due to the selection of papers and books that have been read. But even outside of Vision, important researchers like Chomsky and Jackendoff are both citing Marr. Chomsky positions himself in a *Marr tradition* when he questions probabilistic statistics (Katz, 2012). Jackendoff, when promoting interface rules between combinatorial structure writes about "Like Marr (1982), and unlike Chomsky (1965)" (Jackendoff, 2017, p. 189). As Pizlo points out: Marr himself thought that it is unnecessary to incorporate Gestalt psychology into his own work (Pizlo, 2008, p. 82).

on geometry. This shifted during the research and now a majority is *qualitative,* though often accompanied with some less powerful quantifiers (see chapter 4.2).

Other Vision researcher state that human judgement on quantitative properties gets better when the user can walk around an object, or is presented complimentary photographs from different angles.[78] This is reflected in the empirical data gathering were the participant have always been presented multiple photographs of each World Exposition pavilion.

A Priori Constraints, Context and Pragmatics

The Vision researcher Pizlo stresses that shape is only perceived correctly when it is in context and not isolated down to a single depth cue. This context is similar to the role that Jackendoff grants *pragmatics.* Context will help to solve ambiguity and therefore *helps to see* the shape. A special kind of context are the *a priori* constraints that Pizlo assume to be innate. The most prominent one is *symmetry*. In his work *symmetry* plays especially well together with *gravity*. We will see that by accepting similar constraints on architecture building shape we can simplify the system of an *architecture space* compared to an unconstrained *geometry space*.

Precedence in Architecture

This thesis is not the first attempt to classification of shape for architecture. The author was involved in some technical work on the SDA (see chapter 5.4.3). The *typology of shape* (Loh, 1996) was an early influence and lead to (Jurewicz, 2005).

The three World Exposition pavilions in Figures 39, 40 and 41 are from the SDA building collection. They are also among the 80 pavilions picked for this thesis. They will appear later in the empirical findings in chapter 12.

78 See also end of chapter 7.2 and in chapter 11.1.

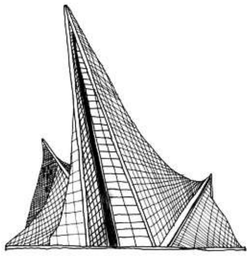


Figure 39: SDA building E 603/2
“Philips Pavilion Expo 58 Brussels”
with single unit building shape
“Cone free form: saddle”

in this document:
“B7 - Expo 1958 Philips Corporate Pavilion (Bruxelles)”

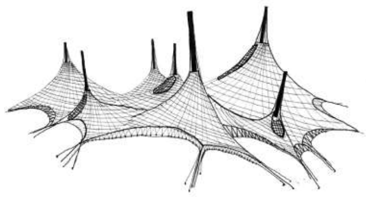


Figure 40: SDA building E 616/1
“German Pavilion Expo 67 Montreal”
with single unit building shape
“Cone: trunc: saddle: inverted: os”

in this document:
“Z1 - Expo 1967 Germany Pavilion (Montreal)”

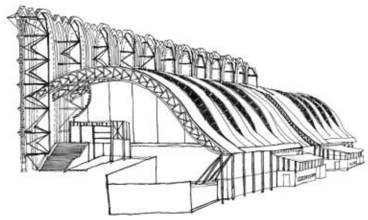


Figure 41: SDA building E 622/4
“Plaza of the Future Expo 92 Seville”
with aggregate building shape
“Vault* trunct: concave: convex/ saddle”

in this document:
“H6 - Expo 1992 Palaza Del Futuro heme Pavilion (Sevilla)”

Early ideas for this thesis did suddenly not fit into the geometrical model. It helped to understand the fundamental difference of physical shape and perceived shape that Arnheim (1974) introduced. This thesis follows the path of *perceived shape* but it does draw on some terminology from *typology of shape*. This is visible in the arrangement of multiple shapes and leads to *Building Shape Syntax Trees*. The description of the shape of a distinct building part is closer to the perceived shape which can be associated with IL 22 (Otto, 1988). This leads to *Building Shape Periphrases.*

6. Classification Overview

This chapter is an overview of the proposed system in this thesis. It gives an introduction and the big picture. This will make it easier to follow the later in depth chapters and see them in the broader context. The objects under investigation are *building shapes* and it is helpful to understand the term *distinct building part* which we defined next. Then this chapter will give a brief introduction to three of the four main concepts: *Classification Items*, *Periphrase* and *Syntax Tree*.

6.1. Distinct Building Parts

A building can consist of one or more *distinct building parts* that contribute to its visual identity. It can additional consist of further, potentially less important parts. The parts can be identified by an observer and have a *building shape*.

What properties define parts? *Size* is important. Though size is not the only driver that defines the identity of an “architecture” building shape. There can be smaller properties that the original architecture team might have carefully emphasised during the design process. This can be considered similar to the way we distinguish humans: for instance the face is of special attention but sometime overruled by other factors like the height of a particularly tall person. Returning to building shapes an analogy might be: E2 - Expo 2010 China Host Pavilion (Shanghai) stands on a huge base that houses most of the exhibition space, still the architecture focus is the upside down pyramid (See Figures 42 and 43). The red colour of the pyramid obviously accentuates this even more, but we will not take colour into account. A similar example is the B5 - Expo 2010 Luxembourg Pavilion (Shanghai) in Figure 44. The iconic tower is surrounded by a less tall but bigger exhibition building.

Figure 42: E2 - Expo 2010 China Host Pavilion (Shanghai)
The grey base vs the iconic red upside down pyramid

Figure 43: E2 - Expo 2010 China Host Pavilion (Shanghai)
Aerial of base (planted with a park) and pyramid

Figure 44: B5 - Expo 2010 Luxembourg Pavilion (Shanghai)
The iconic part is surrounded by exhibition hosting part

A second parameter we can identify is *Level of Detail*. When we look at architecture in the real world, or from photographs, then there are differences to 3D modelling software or visual representations in 3D game engines viewed on a dedicated hardware. In 3D modelling software the Level of Detail is determined by an algorithm and mainly dependent on the size of the building relative to the viewpoint of an observer. This does not fully apply to architecture because it is not always possible to look at a building from a distance. For example in an urban setup the view might be obscured. The empirical part of this research focuses on free standing World Exposition pavilions which circumvent some problems of such urban context. Therefore the proposed classification system works well for these kind of buildings and future additions and empirical data gathering could show if it holds true for other building contexts as well.

Distinct building parts must be identified, to make the proposed classification system work. The identification of parts, and decision that a part is *distinct* is to some degree subjective. Biederman's (1987) recognition by component theory would try to solve this more objectively by looking at concave connection points. Biederman himself admits that sometimes there is a problem with his approach; for instance with the shape of a pencil. The connection between the shaft and the tip of a pencil is continuous. We can assume that all humans that look at shapes and create classification do follow some kind of cognitive rules, like the one proposed by Biederman or alternatives like Pizlo's approach with symmetry. All 80 data models of the World Exposition pavilions in this research were created by the author. Later they are compared to an empirical data set gathered from 52 participants to test if the hypothesis is valid. Ideally this research should be followed up by a test if other humans would apply the same classification. Unfortunately this is out of scope.

Figures 45, 46 and 47 show examples of buildings with more then one clear distinct building part.

Figure 45: D2 - Expo 1967 Africa Group Pavilion (Montreal) "gaps"

Figure 46: D4 - Expo 2010 Wanke Corporate Pavilion (Shanghai) "close packing"

Figure 47: U3 - Expo 1970 Netherlands Pavilion (Osaka) "penetration"

The following Figures 48, 49 and 50 show examples of buildings that are considered to consist of a single building part. Of the 80 world exposition pavilions 27 were identified as only consisting of a single building shape; that is 34% or "one third".


Figure 48: W2 - Expo 2010 Singapore Pavilion (Shanghai)


Figure 49: S2 - Expo 2010 Finland Pavilion (Shanghai)


Figure 50: A1 - Expo 2010 Canada Pavilion (Shanghai)

The following Figures show buildings which are harder to break up and the rational behind each decision.


Figure 51: A2 - Expo 2010 Germany Pavilion (Shanghai) Pedestrian Front View


Figure 52: A2 - Expo 2010 Germany Pavilion (Shanghai) Pedestrian Back View

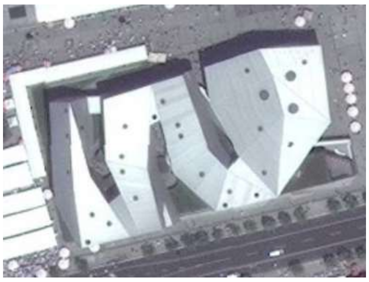


Figure 53: A2 - Expo 2010 Germany Pavilion (Shanghai) Satellite

A2 - Expo 2010 Germany Pavilion (Shanghai) (Figures 51, 52 and 53) – Is the main grey structure made out of three parts or is it one big part which zig-zags? A base is present but it is significantly dominated by the upper part. Especially with the help of the satellite we settle at two distinct building parts: a separate base part and the grey structure is one part with significant valleys as a feature.


Figure 54: E2 - Expo 2010 China Host Pavilion (Shanghai) Pedestrian View


Figure 55: E2 - Expo 2010 China Host Pavilion (Shanghai) Aerial


Figure 56: E2 - Expo 2010 China Host Pavilion (Shanghai) Satellite

E2 - Expo 2010 China Host Pavilion (Shanghai) (Figures 54, 55 and 56) – There is a base, which houses significant parts of the exhibition with indoor pavilions of the Chinese provinces. The 100,000m^2 exhibition space of the base is nearly double the size of floor area of 53,000m^2 of the red rooftop (Deng, 2012). The base is designed in an ambient grey/ivory colour and is dominated by the red structure which is also known as the "Oriental Crown". The base is so big that it is hard to recognize. The base has a different set of shape properties like angles which we can see from aerial and satellite photographs. We settle at six distinct building parts: The upside down red rooftop, four red feet that form a group and the base.


Figure 57: V1 - Expo 1967 Austria Pavilion (Montreal) Pedestrian View 1


Figure 58: V1 - Expo 1967 Austria Pavilion (Montreal) Pedestrian View 2


Figure 59: V1 - Expo 1967 Austria Pavilion (Montreal) Aerial

V1 - Expo 1967 Austria Pavilion (Montreal) (Figures 57, 58 and 59). It is composed of visually strong geometric primitives. One group is lower, a second taller and it is cantilever. We settle at two distinct building parts, mainly because we assume that a pedestrian perspective would support this claim.

6.2. Core Concepts

The hypothesis enumerates four concepts from Linguistics that might help with the complexity of building shape. Each one has a counterpart building shape concept developed in this thesis. The following list shows the mapping:

- Concept 1 – Domain specific vocabulary → Classification Sets
- Concept 2 – Implicit statements → Building Shape Periphrase
- Concept 3 – Lexicon and synonyms → Weak References
- Concept 4 – Syntactic trees and recursive rules → Building Shape Syntax Tree

This section will give a brief introduction to 1, 2 and 4. This should give the reader the big picture, before later chapters go in sometimes exhausting details. Concept 3 – *Named Relationships* is best explained when we discuss comparison of building shapes in chapter 9.3 and is omitted here.

- *Classification Sets* – are groupings of shape related properties that we call classification items.
- *Building Shape Periphrase* – a setup of multiple classification items to describe one distinct building part.
- *Building Shape Syntax Trees* – a setup of multiple Building Shape Periphrases to describe building shapes that contain two or more distinct building parts.

Figure 60 gives an overview of most of the concepts.

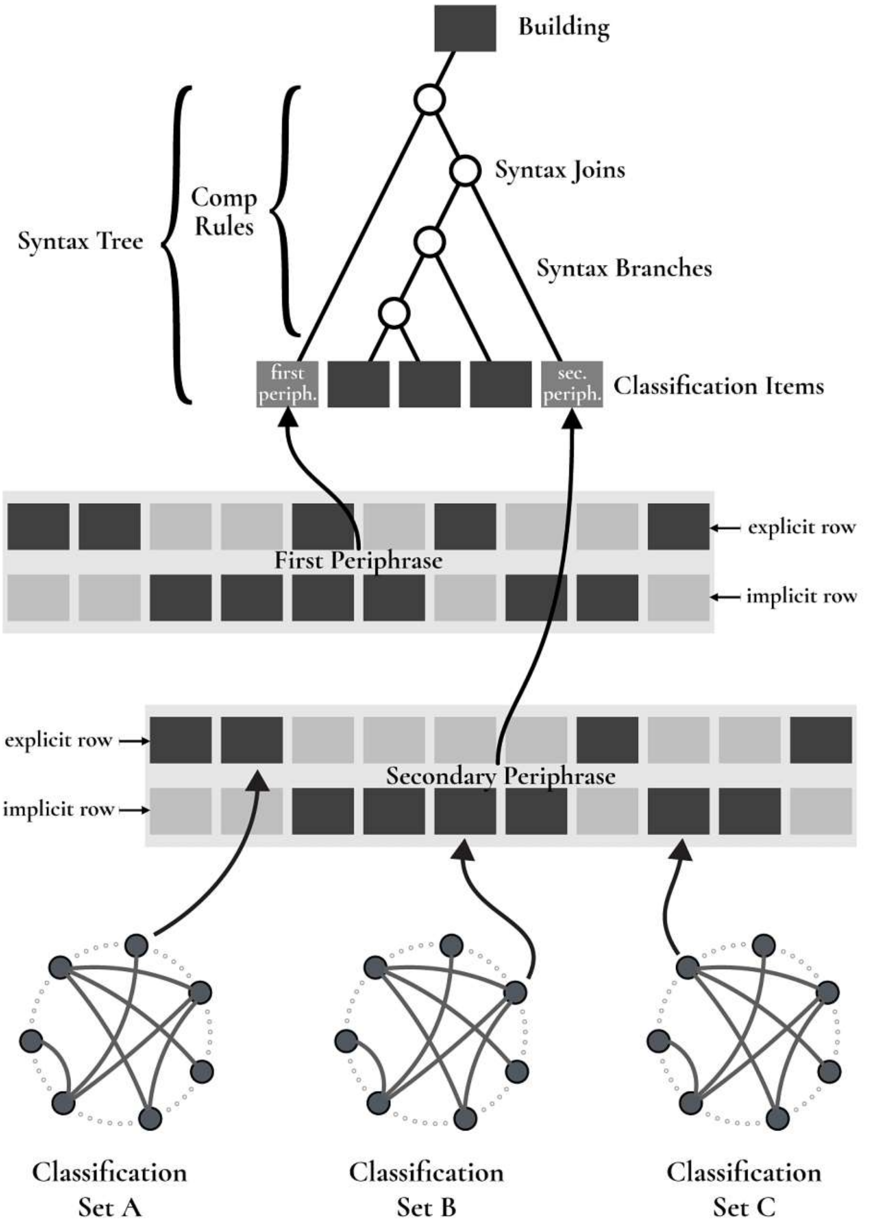


Figure 60: Visualisation of the proposed classification system, with the connections between the different layers. Building Shape Syntax Trees (Top) Building Shape Periphrase (Middle), Classification Sets (Bottom), and Named Relationships (arcs within Classification Set circles)

6.3. Canonical Example: Kaleidoscope

6.3.1. World Exposition Pavilions

The empirical part of this research identifies World Exposition pavilions as a group of buildings with a lot of common aspects. This makes it easier to compare their building shapes with each other. 80 such pavilions have been selected, and they share the following contexts:

- Spatial Context: They are *free standing*.
- Site context: They are on World Expositions sites. Their neighbouring buildings are also pavilions. They are in competition with the other pavilions to attract visitors.
- Application Context: Their purpose is to attract pedestrians to come inside and visit an exhibition.
- Owner Context: They are commissioned by repeating entities. By public entities (like pan-national-organisations, nations, regions or cities), bigger corporations, organisations, national associations or the host nations.
- Time Context: All selected pavilions are from between 1958 (Bruxelles) up to 2012 (Yeosu). The defining historical eras are the *Cold War* (up to 1989) and *Globalisation*.
- Climate Context: All building are in moderate climate zones. They are designed to be used during comfortable weather conditions. There is no need to be fully prepared for usage during cold winter days.
- Lifespan Context: Many buildings are temporary and only have a planned lifespan of six month, during the main event. Though some buildings are designed to last longer and have a new application after the World Exposition.

These commonalities make it easier to focus on just building shape. Of course there are still aspects which distract, like: architectural style, structural system, material, colour, etc. Figure 61 provides a first impression about the types of building shapes that are investigated in this thesis.

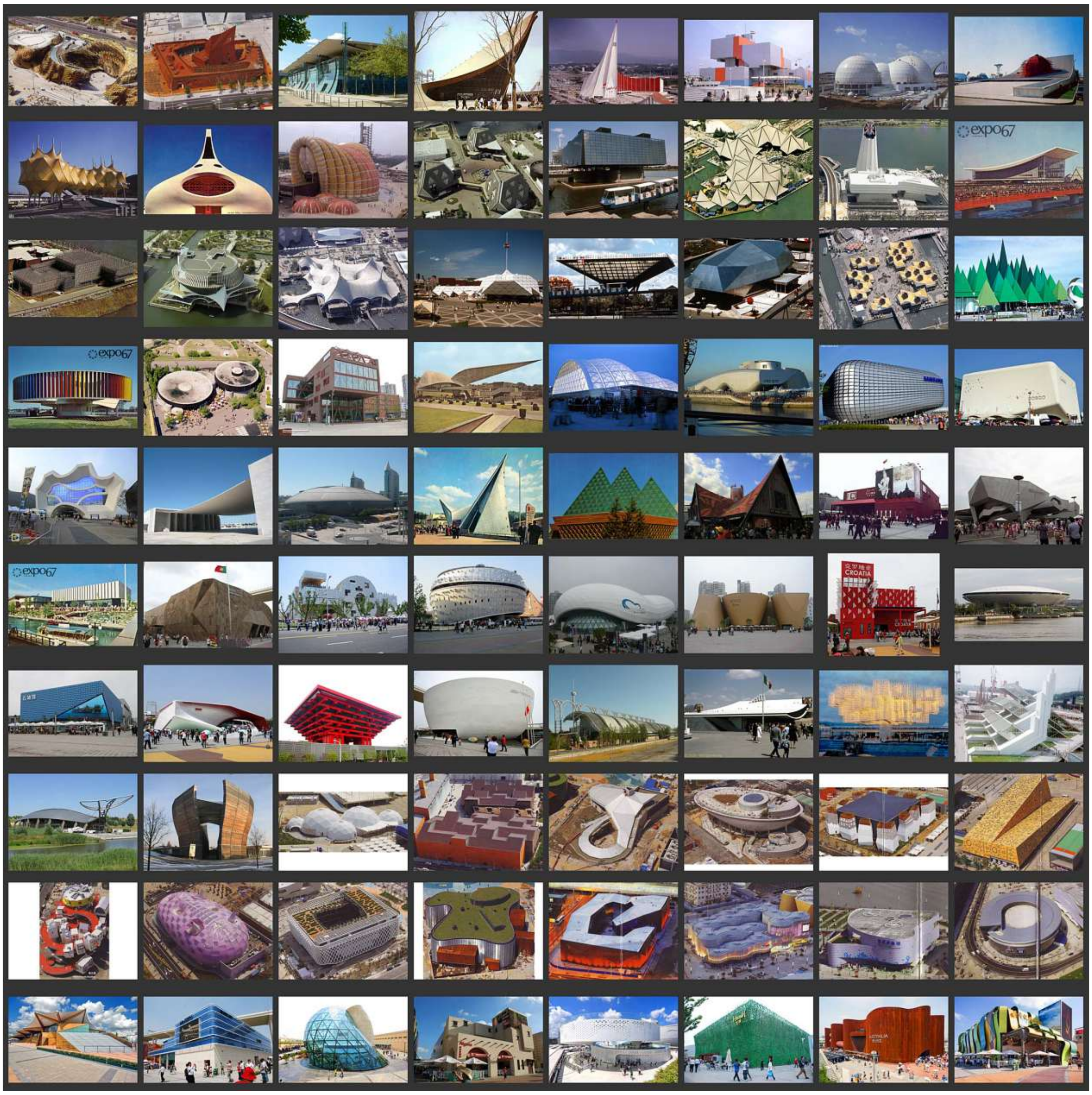


Figure 61: Thumbnails of the 80 World Exposition Pavilions investigated in this thesis.

While 80 buildings seem manageable, with a collection of 600 building shapes as in Figure 62 we already can understand the need for some kind of sorting or classification. This need even grows stronger once such collections hit the “several thousand” threshold. A number not uncommon in bigger European construction companies and bigger planing offices.

When a building is referenced for the first time in a paragraph or section, then we will often use a verbose nomenclature in the text like:

(1) F3 - Expo 2000 Japan Pavilion (Hannover)

(2) some text before F3 - Expo 2000 Japan Pavilion (Hannover) more text

Especially when reading a PDF version of this document, this simplifies finding other text passages where the pavilion is also mentioned. “F3” is a unique pavilion key in this document. Appendix A (19.1) is sorted by the unique pavilion key.

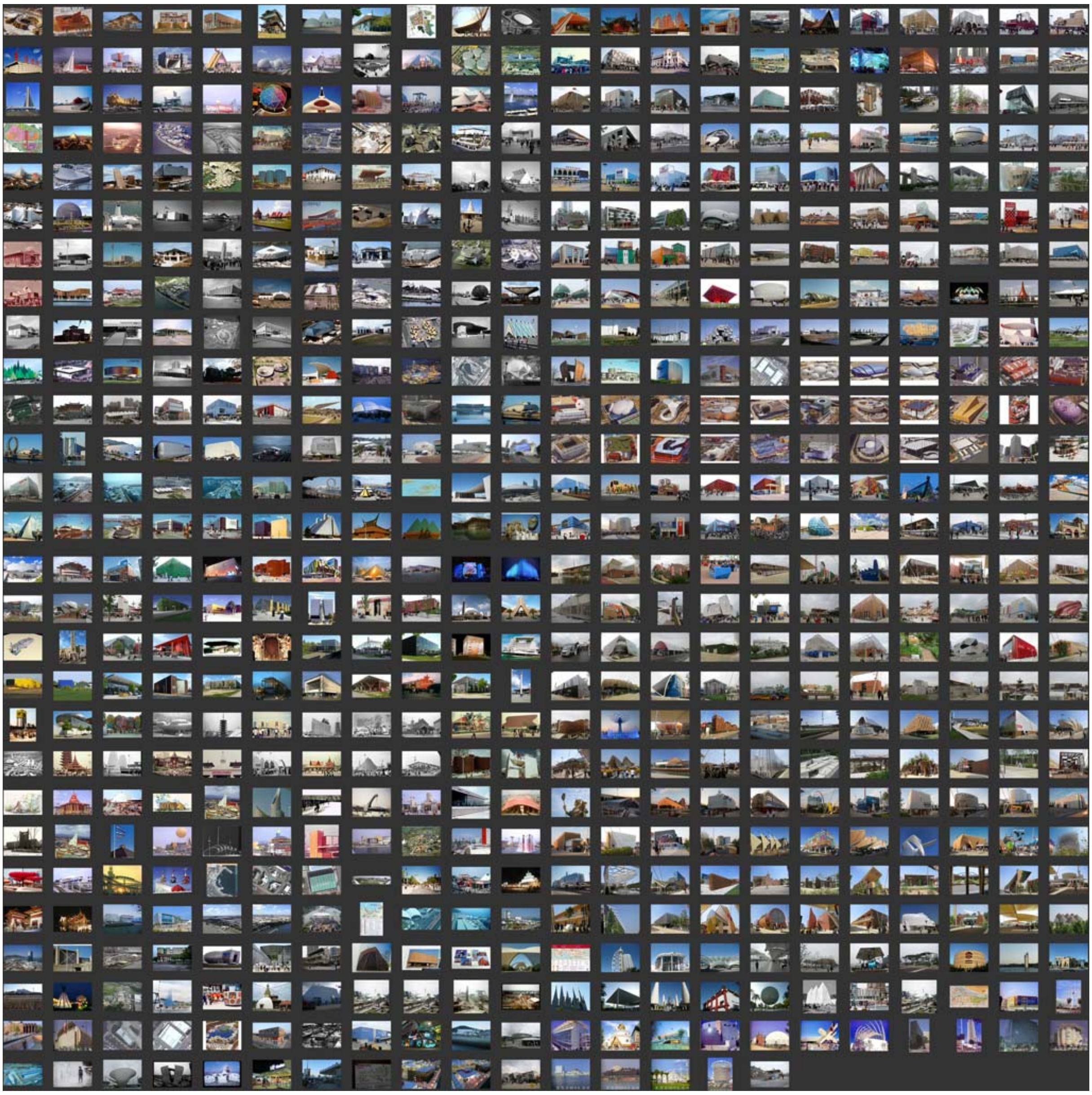


Figure 62: Impression image of the more then 600 World Exposition pavilions that have been considered for this thesis.

6.3.2. Kaleidoscope Pavilion

On the World Exposition 1967 in Montreal there was a pavilion sponsored by the chemical industry called the "Kaleidoscope". It was named after the rainbow coloured stripes and the visual effect (see Figures 63, 64 and 65). It is a good example because it consists of two distinct building parts: a small *base* and what people would commonly identify as a *cylinder*. In the rest of this research we will see that the proposed systems tries to avoid terms from solid geometry, and we will be able to describe these shapes by their properties. But we have a name – *Kaleidoscope* – and two distinct parts – *base* and *cylinder* – which we can name without colliding with the rest of the classification system.

Figure 63: E3 - Expo 1967
Kaleidoscope Pavilion (Montreal)


Figure 64: E3 - Expo 1967
Kaleidoscope Pavilion (Montreal)

Figure 65: E3 - Expo 1967
Kaleidoscope Pavilion (Montreal)

One goal of this research is to describe buildings in a way so that arbitrary building shapes can be compared with each other.

Figure 66 shows that the Kaleidoscope is easy to distinguish compared to other pavilions. We could be asked to describe the building shape of the Kaleidoscope so a third person should select it correctly form the group of six. A single information like “the round one” would most likely be sufficient.

Figure 66: The Kaleidoscope is easy to distinguish compared to other pavilions

When we would be asked to give instructions to another person to pick the Kaleidoscope from the group of six buildings in Figure 67 we might realize that a single property might not be sufficient. We would emphasise certain properties from the *cylinder*and maybe decide that the arrangement with the *base* starts to contribute to the identity when the peer buildings are more challenging.

Figure 67: The Kaleidoscope is not easy to distinguish compared to other pavilions

6.3.3. MAC by Oscar Niemeyer

In a previous paper related to this thesis the author (Jurewicz, 2015, p. 69) used the “Museu de Arte Contemporânea de Niterói” (MAC) by Oscar Niemeyer as an example (See Figures 68, 69 and 70). It is also a good example because it has a clear visual language. But even Niemeyers clean looking shapes have some complexity that can be discussed. Unfortunately the MAC is a museum near Rio de Janeiro and not a World Exposition pavilion. By sticking with the Kaleidoscope we will have the chance to compare it to real empirical data. Both the Kaleidoscope and the MAC show case one of the most interesting classification sets which is *Tilt*.

Figure 68:
Brasil – Niterói – MAC

Figure 69:
Brasil – Niterói – MAC

Figure 70:
Brasil – Niterói – MAC

We can repeat the same comparison with the MAC (Figures 71 and 72). In this case we can see that even features like tilt and cantilever can appear in other buildings as well.

Figure 71: The MAC is easy to distinguish compared to other pavilions

Figure 72: The MAC is not easy to distinguish compared to other pavilions

We assume that we want to be successful and efficient at the given task. Linguists broadly agree that our language capacity strives for optimizes recursive information representations. The way we offer the information to a third person would therefore adapt to the context. We would provide different amounts of information in different contexts. This could be a hierarchical reduction and expansion which might be similar to Marr (chapter 5.3.1) or the reduction done by Lerdahl and Jackendoff (chapter 5.2). The later team has been able to reduce classical music to the dominant notes and a test audience would “prefer” this interpretation to be closer to the original piece of music, over alternative flawed reductions.

When the task is to rank buildings how similar their building shape is to the Kaleidoscope then a single reduction/expansion is not sufficient. The comparison must be done for every candidate. This is the goal of chapter 9 and the choice of data structure must cater that need.

We will also look into buildings shapes which might not follow geometric primitives like cube, cylinder and sphere. One such comparison pair will be the A1 - Expo 2010 Canada Pavilion (Shanghai) and A2 - Expo 2010 Germany Pavilion (Shanghai).

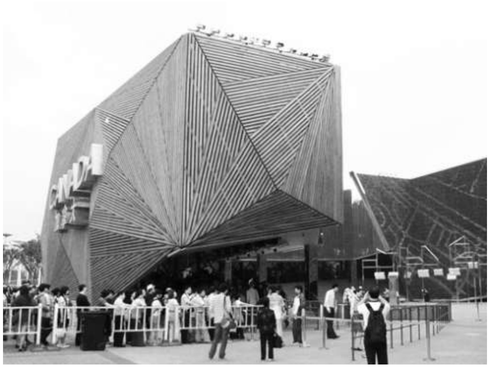


Figure 73: A1 - Expo 2010 Canada Pavilion (Shanghai)

Figure 74: A2 - Expo 2010 Germany Pavilion (Shanghai)

6.4. Classification Sets

The glossary definitions:

- *Classification Item* – is either a text keyword or a *sketch* that can be used to index a *building shape*. It is usually grouped with related items in a *classification set*.[79]
- *Classification Set* – a group of *classification items* that have common properties. Classification sets are related to custom tailored domain vocabularies. For example: all *items* that describe *curvature*.

Classification items are defined as properties of buildings shapes that can be identified. Examples might be a faceted texture, a convex curvature, a high point, or a certain proportion. It makes sense to group related items. For example convex curvature, concave curvature and the absence of a curvature can be grouped into a *Curvature set*. In computer science the term *set* describes a group of related items where all members are distinct and the sorting order is arbitrary. Chapter 9.3 will show that the technical implementation chosen to represent sets is capable to provide additional functionality like cross references.

There are three families of sets.

79 Classification items have a technical name. This technical name is provided in a “camel case” text style. In chapter 6 we see it mostly in Figure captions. We will see the use of the technical names increase starting with chapter 7, where it is styled with a light grey background colour like curvatureConvexConcave , when it appears in the main text.

- Sets that can be applied to *one distinct building part* like Curvature and Texture. These are used in Building Shape Periphrases
- Sets for composition of distinct building parts, like Spacing and Relative Size. These are used in Building Shape Syntax Trees
- Cross cutting sets like Symmetry and Axis.

6.4.1. Included Sets

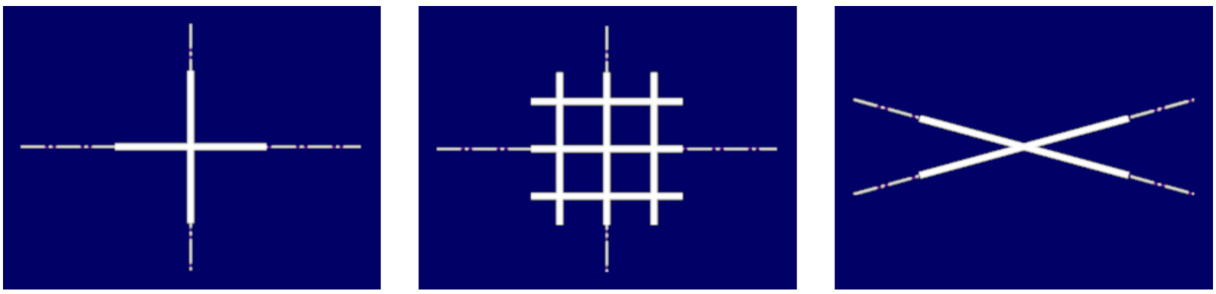
The family of sets for *one distinct building part* include: Angle, Edge, Tilt, Curvature, Texture, Feature, Lattice and Proportion. An overview will be provided in chapter 6.5.2. A full definition will be in chapter 7.3.

The family of sets for *composition* of distinct building parts include: Spacing, Cardinality, Orientation, Variety, Relative Size, and Size Randomness. An overview will be provided in chapter 6.6.3. A full definition will be in chapter 8.2.

Cross cutting sets are: Symmetry (Figure 75), Axes (Figure 76), and Cardinality. Conceptually they are included in the proposed system. Unfortunately Symmetry and Axes are missing in the current software implementation because they introduce some complexity that would require additional time and resources. Chapter 8.4 shows their theoretical role in Periphrases and Syntax Trees.

a: reflection b: rotation c: translation

Figure 75: Examples of symmetry.



a: two perpendicular b: multiple perpendicular c: not perpendicular

Figure 76: Examples of axes layouts.

Cardinality[80] is actually a cross cutting set but in the current software implementation it is only used in the Syntax Tree part. On the other side Proportion and Lattice sets are in the current software implementation only used in the Periphrase part but could be theoretically also applied to the Syntax Tree part. The 80 World Exposition pavilions are representing only a fraction of what is possible within architecture. Additional buildings could be added that make heavy use of Proportion and Lattice (deformations) in the Syntax Tree part in the future. In such a scenario an enhanced software implementation could enable them in the Syntax Tree as well.

6.4.2. Omitted Sets

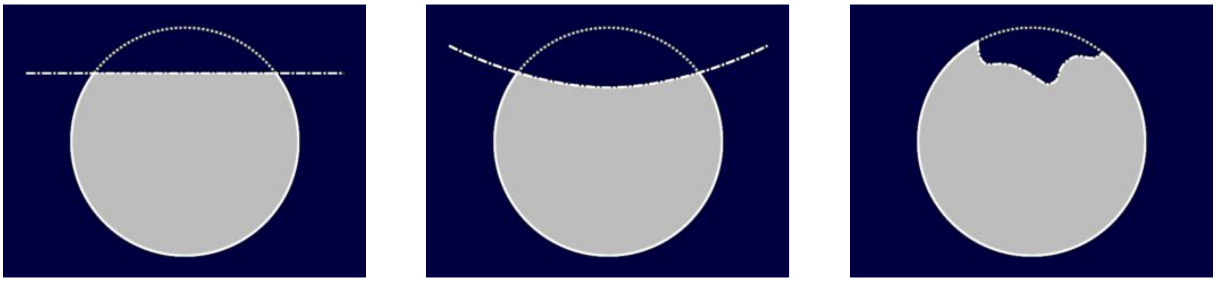
Often it is revealing to look at what is missing.

3D Solid geometry, 3D surface geometry and 3D wireframe geometry are omitted (Figure 77). 2D geometries, typical in the description of ground plans and elevations plans in architecture, are omitted as well. These omissions are intentional and will be reasoned about in chapter 7.

Figure 77: 3D geometry representations

It is possible to create a classification set for *truncation* like in (Jurewicz, 2005) (Figure 78). But truncation works closely with the above mentioned geometry sets and was therefore also omitted. Truncation and trims are an important part in Constructive Solid Geometry (CSG) and NURBS based geometry. As mentioned in chapter 1.2, these are valid approaches for physical shape but this thesis handles only keywords and sketches for *perceived* shape. Though there is the real world architecture concept of a *court* in buildings. A court could be described as a truncation. This is a repeating case in some World Exposition pavilions used in the empirical part of this research. The partial solution is to add *court,* as a special case of a *low point,* into the aptly named “Feature” set.

80 Cardinality is a mathematical term to refer to the number of elements in a set. Think of “1”, “2”, “3”. Amount or count are synonyms for cardinality.



a: straight cut away (frame0161) b: concave cut away (frame0166) c: irregular cut away (frame0152)

Figure 78: Examples of Truncation

Colour, *material* and *transparency* are omitted to keep the scope for this research manageable. The participants in the empirical data gathering were explicitly asked to ignore these properties. There was even an attempt to only show black-and-white images. The black-and-white images have been reverted back to their original coloured versions. Especially in old historic low resolution images, black-and-white made it hard to distinguish the building shape from background objects or neighbouring buildings.[81]

An architecture space can be defined not only with enclosing objects, but also by more subtle means. Hinting that a certain shape is present and let the visitor complete the shape in the mind. Transparency can not only be achieved by the use of glass material but also by the density of the first outer skin layers of a facade (Figures 82, 83 and 84). These are very attractive properties in applied architecture and architecture theory but are unfortunately out of scope for the building shape classification in this research.

Corners are the points edges merge. But they are currently omitted. They appear to be to fine grained for a classification set.

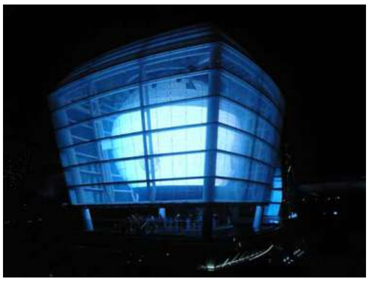


Figure 79: transparency with glass; inside is a sphere; Expo 2010 Taiwan Pavilion (Shanghai)

Figure 80: transparency with glass; inside is a textile structure; Expo 2010 Belgium Pavilion (Shanghai)

Figure 81: transparency with glass; inside is a hot air balloon; Expo 2012 – Lotte Corporate Pavilion (Yeosu)

81 A Figure Ground Organisation (FGO) problem in the Gestalt methodology.


Figure 82: transparency by density; Expo 2010 United Kingdom Pavilion (Shanghai)


Figure 83: transparency by density; Expo 2012 – Caltex Corporate Pavilion (Yeosu)


Figure 84: hinting a sphere Germany Ruhrgebiet Halde Hoheward Horizont Observatorium

6.5. Building Shape Periphrase Overview

6.5.1. Main pattern: Circumlocution

The choice of the word *Periphrase* will be explained at the start of chapter 7. For this overview section we will focus on the fact that we are describing building shape without a direct reference to a geometric archetype. The term geometric archetypes is used to group: spheres, cones, cylinders, perpendicular prisms, pyramids, cubes, Platonic polyhedra and Archimedean polyhedra.

This approach origins from findings during the manual classification of the 80 World Exposition pavilions. No apparent set of geometric archetypes emerged for this collection of buildings. Geometric archetypes did not dominate the identity of many building shapes and at the same time they are replaceable for the calculation of similarity. One reason might be rooted in the selection of buildings them self. A World Exposition pavilion is a special type of building (see chapter 6.3.1). Therefore the *Building Shape Periphrase* concept might only apply in this scope, and be limited to these kind of buildings, but it looks promising that it has a wider valid reach.

6.5.2. The Ten Classification Sets

With the absence of geometry archetypes like sphere, pyramid, cone, and cube, the softer qualitative properties of a building shape get a more prominent role. Each distinct building part is attributed with at least ten classification items from ten classification sets. Therefore we can describe these as ten *slots;* for instance the *Tilt slot*.

The ten classification sets can be further divided into these groups:

- Viewpoint-Dependent on "Plane": Angle, Edge
- Viewpoint-Dependent on "View": Angle, Edge, Tilt
- Viewpoint-Independent: Texture, Curvature, Feature, Lattice

- Gravity-Dependent: Proportion

The titles of the groups already hint that discussing building shape is different to discussing geometric shape. While geometry exists in a void, buildings are constraint by nature. On earth, gravity can not be turned off. Humans have no x-ray vision, so they can only look at shapes that are not obfuscated; and not e.g. under ground or inside. The human scale limits the theoretical size of objects that we perceive as real buildings. The set of World Exposition pavilions is within a common range regarding their size.

The classification sets Angle and Edge for the groups *plane* and *view* are very similar. We will write them with a dash, like Angle-Plane, Angle-View, Edge-Plane, Edge-View to avoid ambiguity. Tilt is only considered in the vertical view.

Front, left side, right side and *back* are reduced to just *view*[82]. This reduction simplifies the data model and is partly enabled by the fact that World Exposition buildings are on World Exposition sites with dozen of other pavilions. It is often possible for pedestrians to walk around them. Some pavilions might have a dominant side but in many cases this is a corner, so two sides are important at once like in Figures 85, 86 and 87. A generalization that "the main entrance defines the front" is also problematic for World Exposition pavilions as in some cases the entrance is located at the back or is just a small door with little architectural emphasis.[83]

Figure 85: prominent corner
A2 - Expo 2010 Germany Pavilion (Shanghai)

Figure 86: prominent corner
H7 - Expo 2000 Hungary Pavilion (Hannover)

Figure 87: prominent corner
B5 - Expo 2010 Luxembourg Pavilion (Shanghai)

The group of *viewpoint independent* classification sets is even less constraint. There is no distinction between "plane and view". Therefore there is no distinction between "roof and wall". So if a person assigns a Texture "faceted" or a Curvature of "convex and straight" there is no indication if this is applied to a wall or a roof. This reduction was introduced to better cater contemporary architecture where the definition of a wall or a roof is often less strict.[84]

82 Biederman came to a similar assumption; see chapter 5.3.2.

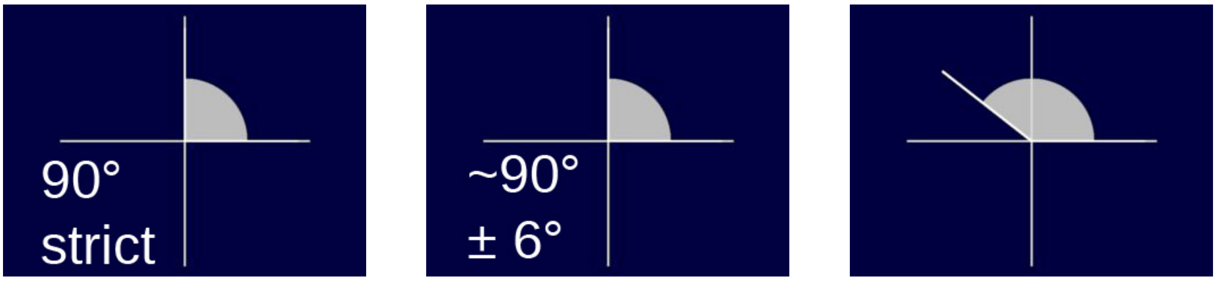
83 Examples of pavilions where the entrance is rather hidden are: Expo 2015 Germany Pavilion (Milan), Expo 2015 United States Pavilion (Milan), A2 - Expo 2010 Germany Pavilion (Shanghai). In many cases flow control of a huge number of visitors with a one way system is more important then one main entrance and exit.

84 In retrospective the missing of "wall and roof" is identified as a future validation task in the findings 13.1.4.

The group of *gravity dependent* consist of just the Proportions set. While there is a decision to ignore front and side within proportions there is always an up and down. Otherwise it would be impossible to distinguish between a high rise building and a long hall or a train station.

The following pages outline each of the ten classification sets and showcases some prominent members together with associated photographs from real buildings. For a consistent and convenient overview each classification set starts on a new page. Exhausted definition and details are given in chapter 7.3.

Angle-Plane and Angle-View



a: anglePerpendicularStrict b: anglePerpendicularOffMinor c: angleObtuse

Figure 88: Three items from classification set Angle-Plane as well as Angle-View

Figure 89: Applied anglePerpendicularStrict in both: plane-angle and view-angle

U2 - Expo 2010 Hamburg Urban Pavilion (Shanghai)

Figure 90: Applied anglePerpendicularOffMinor in both: plane-angle and view-angle

B5 - Expo 2010 Luxembourg Pavilion (Shanghai) (surrounding building)

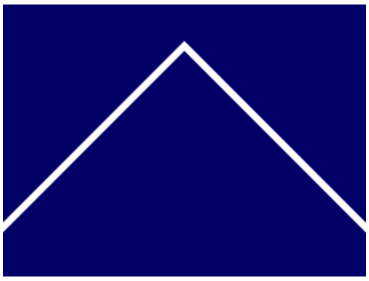
Figure 91: Applied angleObtuse in both: plane-angle and view-angle

X3 - Expo 1970 France Pavilion (Osaka)

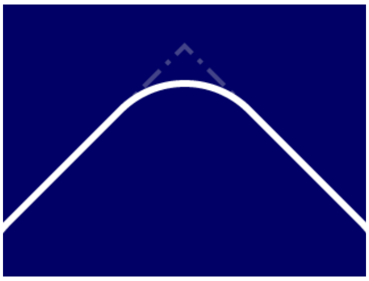
Angle-Plane (Figure 88). The 90 degree angle is important in architecture and can be connected to culture and pragmatic use of technology. Also the absence of 90 degree angles is often a deliberate design statement. The presence of predominantly obtuse angles also drives certain building shapes.

Angle-View (Figure 88). Most of the arguments for View-Angle are the same as for Angle -Plane. But we should remember that the 90 degree angle in a view can be connected with the natural force of gravity and not only culture and technology.

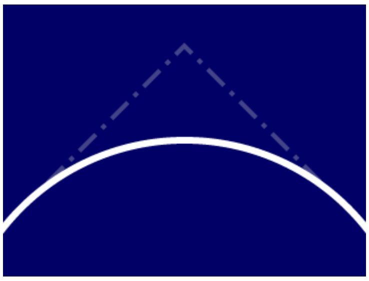
Edge-Plane and Edge-View



a: edgeSharp



b: edgeFillet



c: edgeSmooth

Figure 92: Three items from classification set Edge-Plane as well as Edge-View

Figure 93: Applied edgeSharp

D7 - Expo 1970 Bulgaria Pavilion (Osaka)

Figure 94: Applied edgeFillet

T1 - Expo 2012 Samsunung Corporate Pavilion (Yeosu)

Figure 95: Applied edgeSmooth

X3 - Expo 1970 France Pavilion (Osaka)

Edge-Plane (Figure 92). Sharp edges are common in building shapes and the use of fillet or chamfer edges is usually a design statement. Also the deliberate avoidance of edges to create smooth continues shapes can be considered a design statement.

Please note that the simple visualisation chosen for Edge in Figure 92 is actually a sketch of a corner, or a cut through an edge at a perpendicular angle. A 3D rendering of a *continuous edge* might be a better visualisation, and could be an improvement in a future version.

Edge-View follows the same reasoning as Edge-Plane.

Tilt

a: tiltTaper b: tiltApproximatelyNone c: tiltWiden

Figure 96: Three items from classification set Tilt

Figure 97: Applied tiltTaper

A7 - Expo 2010 Poland Pavilion (Shanghai)

Figure 98: Applied tiltApproximatelyNone

H3 - Expo 2010 Australia Pavilion (Shanghai)

Figure 99: Applied tiltWiden

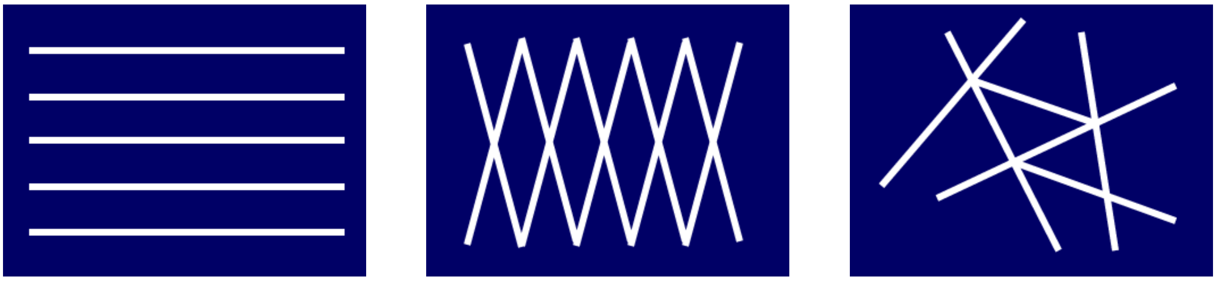
E1 - Expo 1967 Canada Host-Pavilion (Montreal)

Tilt (Figure 96), actually Tilt-View. The distinction between taper and widen is dependent on gravity. People have an equilibrium sense and can not only see, but also feel tilts. The absence of tilt is usually just an upright wall.

Tilt-Plane combination is theoretically possible. It is omitted in the classification data and the software implementation. To work well it requires that there are trapezium like shapes in the plane. Therefore two line of the trapezium must ideally be parallel while the other are converging. In Tilt-View these parallel lines are provided for free as parallel lines to the horizon. In Tilt-Plane the choice of these lines is ambiguous. A pedestrian user can not see all sides of a building at once. It would heavily rely on satellite and aerial footage and it is doubtful that pedestrian user can identify the common items.

Though striking variations, like a very sharp corner could potentially be identified by a pedestrian. These variations are covered partly by the Angle-Plane classification set, as it has some overlap with Tilt.

Texture



a: textureStripedRegular b: textureFacetedRegular c: textureFacetedIrregular

Figure 100: Three items from classification set Texture

Figure 101: Applied textureStripedRegular

E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)

Figure 102: Applied textureFacetedRegular

X1 - Expo 2010 Innovative Tours Theme Pavilion (Shanghai)

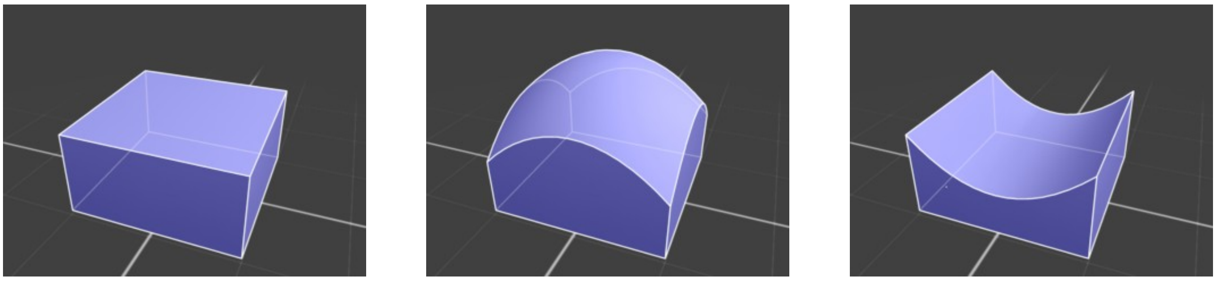
Figure 103: Applied textureFacetedIrregular

A6 - Expo 2010 Portugal Pavilion (Shanghai)

Texture (Figure 100) must be perceived spatially, as opposed to a printed pattern. It is usually at a smaller scale then the rest of the shape.

For example it makes it possible to do classification of a geodesic dome. The geodesic dome might be perceived round, but at a different scale it is created out of planar elements. Curvature would be the dominant information about the geodesic dome, and Texture would support and augment it.

Curvature



a: curvaturePlanar b: curvatureConvexConvex c: curvatureConcaveStraight

Figure 104: Three items from classification set Curvature

Figure 105: Applied curvaturePlanar

U2 - Expo 2010 Hamburg Urban Pavilion (Shanghai)

Figure 106: Applied curvatureConvexConvex

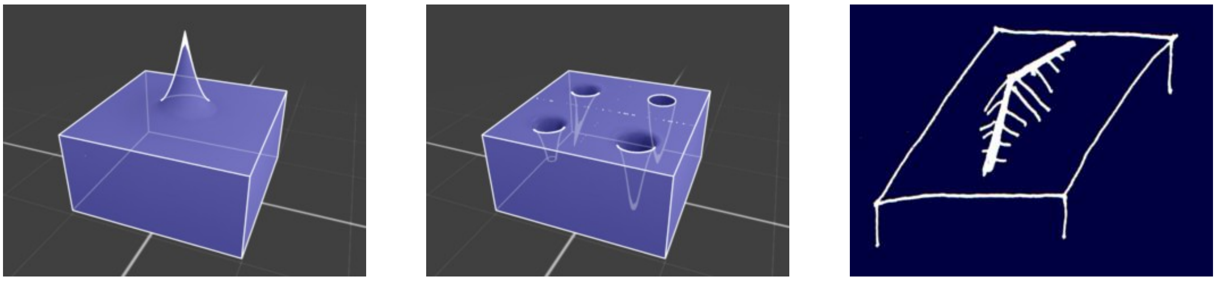
F2 - Expo 2010 Japan Pavilion (Shanghai)

Figure 107: Applied curvatureConcaveStraight

G1 - Expo 1967 Soviet Union Pavilion (Montreal)

Curvature (Figure 104) can be expressed in terms of convex, concave and the neutral straight. While the terms are quite abstract sketches are easier to understand.

Feature



a: featureHighpointSingle b: featureLowpointMultiple c: featureRidgeSingle

Figure 108: Three items from classification set Feature

Figure 109: Applied featureHighpointSingle

B1 - Expo 1970 Soviet Union Pavilion (Osaka)

Figure 110: Applied featureLowpointMultiple

Z1 - Expo 1967 Germany Pavilion (Montreal)

Figure 111: Applied featureRidgeSingle

B3 - Expo 1970 Philippines Pavilion (Osaka)

Feature (Figure 108). In most cases a feature is a deliberate design intervention by an architect. The term *feature* may sound quite broad, but the classification set is mostly focused on high points, low points, ridges, valleys and courts.

Lattice

a: latticeShear b: latticeNoise c: latticeTwist

Figure 112: Three items from classification set Lattice

Figure 113: Applied latticeShear

B3 - Expo 1970 Philippines Pavilion (Osaka)

Figure 114: Applied latticeNoise

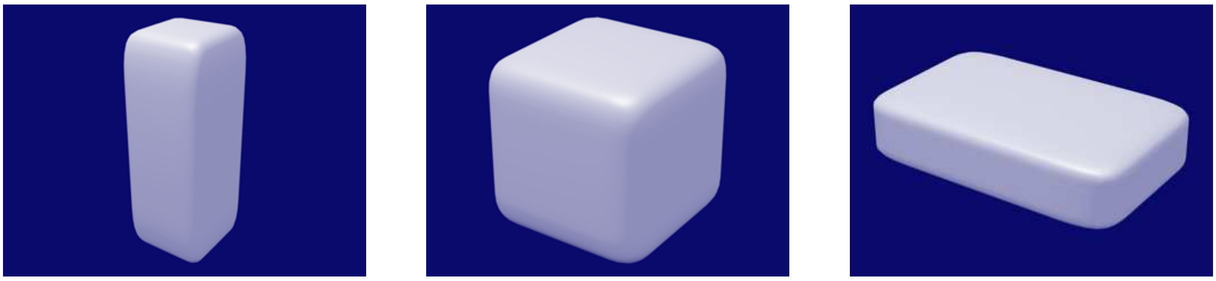
A6 - Expo 2010 Portugal Pavilion (Shanghai)

Figure 115: Applied latticeTwist

C5 - Expo 2010 Israel Pavilion (Shanghai)

Lattice (Figure 112). The term is used in 3D modelling software to describe a transformation that is applied on the bounding box of an object as a whole. For instance a building could be twisted or bend like C5 - Expo 2010 Israel Pavilion (Shanghai). One prominent example for lattice-twist is the “Turning Torso” high rise building in Malmö. Noise could be added to a calm simple geometry.

Proportion



a: proportionZeroZeroP2 b: proportionZeroZeroZero c: proportionP1ZeroM2

Figure 116: Three items from classification set Proportion

Figure 117: Applied proportionZeroZeroP2

B2 - Expo 1967 United Kingdom Pavilion (Montreal) (tower structure)

Figure 118: Applied proportionZeroZeroZero

H7 - Expo 2000 Hungary Pavilion (Hannover)

Figure 119: Applied proportionP1ZeroM2

G1 - Expo 1967 Soviet Union Pavilion (Montreal)

Proportion (Figure 116), makes it possible to distinguish between a high rise and a hall. Proportion usually describes a bounding box.

6.5.3. Assigning Classification Items

Assigning at least ten classification items on each distinct building part is a lot of effort. Therefore the software will create a canonical representation and will fill in each missing slot with a default item. When no classification items are provided by a human, the software will assign all items necessary to describe a *perfect cube* (Figure 120): 90 degree angles, sharp edges, no tilt, no texture, no curvature, no feature, no lattice transformation and one-by-one-by-one proportions (Figure 121). We use the term *perfect cube* as a convenient and easy to remember identifier for these properties. There is no deeper philosophical or geometrical meaning or claim implied.

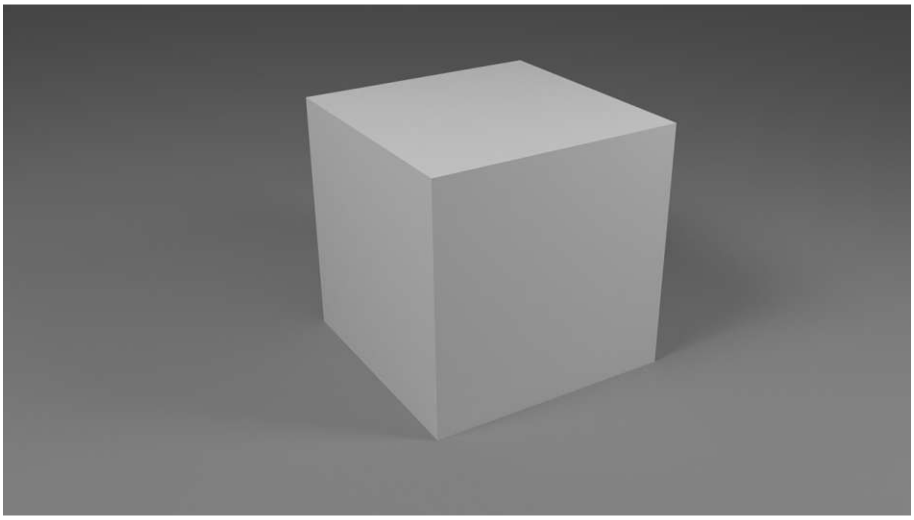


Figure 120: "Perfect Cube"

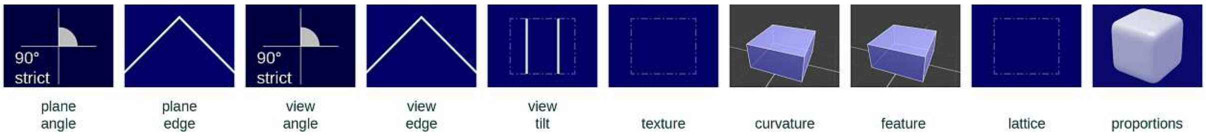


Figure 121: The ten classification sets with their default items that help to describe the "perfect cube"

First computation test runs to compare two building shapes data models made it evident that the ten classification slots can not always be of equal weight. There must be a way to emphasise the significance of certain classification items. This is achieved by annotating the assignment with an attribute that can only have predefined values like *significant* or *minor*. This allows to push or mute the contribution to the calculated result.

During the manual classification work it became apparent that even one distinct building part can have more then one tilt, curvature or dominant angle, etc.. Therefore the system allows to assign more then one item from the same set. There is no exhaustive classification. Human filtering is involved. A blob like building might have a single small planar wall or a few 90 degree angles but the vast majority are obtuse angles. In such cases this secondary information is dropped. This human intervention and judgement differs from a computer algorithm that inspects a 3D model and would need precise instructions or a good machine learning setup.

To avoid repetition and add flexibility it is possible to annotate a classification item assignment with a *behaviour* attribute:

- *override*: the item assigned by a person overrides the implicit default value for the slot. This is the standard and can be omitted.
- *add:* the item assigned by a person is added to the slot. The slot now contains two items: the explicitly assigned item and the implicit default item.

6.5.4. Periphrase Kaleidoscope Example

We can take the Kaleidoscope and look at its two distinct building parts: The cylinder and the base. The cylinder has the following slots:

- Angle-Plane:	*obtuse*	(significant)
- Edge-Plane:	*smooth*	(significant)
- Angle-View:		omitted (defaults to *strict 90 degree*)
- Edge View:		omitted (defaults to *sharp edges*)
- Tilt:	*view-from-below*	(additive, there is also the default *no tilt*)
- Texture:	*regular stripes*	
- Curvature:	*convex-and-straight*	(significant)
- Feature:		omitted (defaults to *no feature*)
- Lattice:		omitted (defaults to *no lattice transformation*)
- Proportion:	*equal-sides-significantly-reduced-height*	

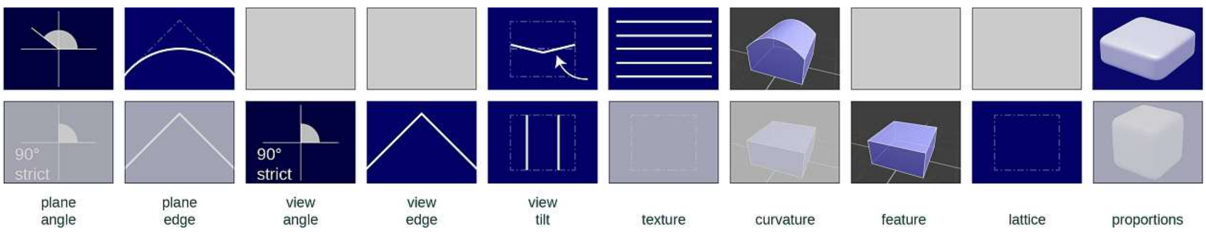


Figure 122: Assigned classification items of the Kaleidoscope part "cylinder". The upper row shows explicit items assigned by a person. The lower row shows implicit default items. Faded items in the lower row are "overridden" while the "tilt" slot has a "add" behaviour. This slot consists of the explicit and the implicit classification items.

Figure 122 shows the sketches for the cylinder part of the Kaleidoscope. These are the same as the above enumerated italic text terms. After a short time the sketches[85] are easier to "read". Especially when the sequence is always the same. The Curvature text term "*convex-and-straight*" describes the curvature but the sketch in Figure 122 is easier to understand. This becomes obvious when looking at the proportions text term "*equal-sides-significantly-reduced-height*" compared to the sketch which is easy to understand. Later in this thesis[86] we will start to include technical names and reference them in the text paragraphs. Some of the technical names are straight forward: "*convex-and-straight*"

85 See Glossary definition in chapter 2.

86 We already see these technical names in the captions of Figures that show classification item sketches. For example Figures 112 and 116.

becomes curvatureConvexStraight. But some technical names are challenging: "*equal-sides-significantly-reduced-height*" becomes proportionZeroZeroM2.

We describe the geometric archetype of a *right circular cylinder* without referring to it by means of any strict geometric classification set. We use circumlocution and identify six[87] characteristics which are present in a right circular cylinder. *Obtuse* angles and *smooth* edges when looked from top; *strict 90 degree* angles and *sharp* edges when looked from the side; upright walls defined by *no tilt*; a *convex-and-straight* curvature. When we are given these six properties it would still be possible to imagine other valid building shapes. The addition of symmetry and axis information would further lock down towards a right circular cylinder.[88]

We can argue that from an aerial photography it is possible to see that the cylinder is not a solid body. It seems to be made up by the cylindrical skin, a few boxes and some voids. So the decision to just describe a cylinder is a human decision and could be challenged.

We can repeat the same procedure for the *base* of the Kaleidoscope. This is the small distinct building part on which the big cylinders sits (see Figure 123):

- Angle-Plane:	*obtuse*	(significant)
- Edge-Plane:	*smooth*	(significant)
- Angle-View:		omitted (defaults to *strict 90 degree*)
- Edge-View:		omitted (defaults to *sharp edges*)
- Tilt:		omitted (default to *no tilt*)
- Texture:		omitted (defaults to *sharp edges*)
- Curvature:	*convex-and-straight*	(significant)
- Feature:		omitted (defaults to *no feature*)
- Lattice:		omitted (defaults to *no lattice transformation*)
- Proportion:	*equal-sides-reduced-height*	

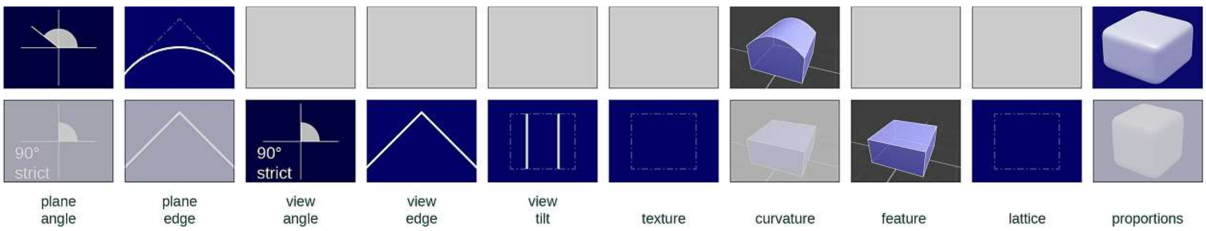


Figure 123: Assigned classification items of the Kaleidoscope "base". The upper row shows explicit items assigned by a person. The lower row shows implicit default items.

We can observe that we are again close to describe a cylinder. But we lack detailed photographic footage to really see how the details are constructed.

87 Some of these items are from the explicit group, other from the implicit group with the default items. Not all explicit items are necessary for a right circular cylinder. From a geometric point of view proportion do not alter the definition of a cylinder.

88 Symmetry and Axis are discussed in chapter 8.4.

When we closer inspect historical photographic footage, we can identity a ramp that visitors take. A set up similar to the MAC by Niemeyer, but more hidden. Again it is a human decision to ignore the ramp and not define it as a distinct building part. This could be challenged. In a case study that focuses on round cantilever buildings, the ramp might have an important role, but for the task to compare the overall building shape it can be argued otherwise[89].

We have been able to assign classification items to the cylinder and the base of the Kaleidoscope, but we need a way to describe how the two distinct building parts relate to each other.

6.6. Building Shape Syntax Tree Overview

6.6.1. Main Pattern: Headed Binary Tree

When we look at the 80 World Exposition pavilions that have been analysed for the empirical part we recognize that 27 consist only of a single distinct building part, but the other 53 have multiple parts. The parts might have

- different visual design importance (Figure 124)
- the same distinct building part might appear in many variations (Figure 125)
- a group of small buildings might be considered one pavilion. Two examples for such distributed building complexes are D2 - Expo 1967 Africa Group Pavilion (Montreal) (Figure 126) or the cluster pavilions on the World Exposition in Milan 2015.

Figure 124: Different visual importance
E2 - Expo 2010 China Host Pavilion (Shanghai)

Figure 125: One distinct building part appears in variations
A4 - Expo 2010 Russia Pavilion (Shanghai)

Figure 126: Many buildings form one pavilion
D2 - Expo 1967 Africa Group Pavilion (Montreal)

Composition of building shapes is a tool in the repertoire of architects and a system for building shape classification should try to handle it.

89 Ramps are quite common in World Exposition pavilion as they allow to guide a huge audience through a multi level exposition.

At the level of only one distinct building part this thesis introduced the Building Shape Periphrase[90]. It works with circumlocution and a flat list of at least ten required classification items. For the Kaleidoscope we can describe the big cylinder and the small base below it, with the help of two Periphrases.

The two distinct building parts of the Kaleidoscope are obviously of different visual impact and their arrangement is special as well: a smaller element carries a bigger element.

The previous English sentence could be rewritten in a few more delimited statements:

- The parts have partial contact which is a quite common spacing arrangement.
- The composition contains two distinct building parts. The cardinality of 2 augments and constrains the previously mentioned spacing arrangement.
- The orientation is special and significant. It is upside down. The orientations augments and constrains the previously mentioned spacing arrangement.
- The base is of a relative smaller size then the cylinder above it.
- The base is there, but it is not so important. It is a minor element in the architecture design.

Lets hypothetically imagine that there would be a small dome on top the big cylinder (Figures 127 and 128). Again we could describe this distinct building part with a Periphrase. The composition would be similar to the one of the base but the orientation would be vertical on-top instead of up-side-down. Because our dome sits prominently on top of the big cylinder we might consider it more important then the small base but still the most important part is the cylinder.

Figure 127: E3 - Expo 1967 Kaleidoscope Pavilion (Montreal) as it was build

Figure 128: Kaleidoscope photomontage with an additional dome structure on the top.

Deciding which is the dominating part is in the eye of the beholder. Various sources might be able to answer this with more authority: The architect that did the original design, or the owner of the building, or its users that participated in an empirical survey. A careful case study by a person with a background in architecture theory that knows about additional context might also be able to give a qualified answer. But this is infor-

90 From now on the abbreviation "Periphrase" will be used.

mation that is often not available. Sometimes it might be accessible but uses a language that is closely tied to a case study.

6.6.2. The Headed Tree Structure

The main data structure for the composition of distinct building parts will be a binary tree. A binary tree is a well known data structure in computer science. It restricts that at a branching point there can only be two child branches. Because we are interested in the reduction we flip the tree upside down for our data visualisations. The root point at the top represents the building shape of a real building. All branches below are the abstractions that try to describe the building shape. The straight lines are called *axes*. The points where branches merge are called *nodes*. The use of an upside down tree is inspired by cognitive linguistics as described in chapter 5.1.

The binary tree will be *headed*. One of the branches is more important then the other, and it is dominating the other branch. When a reduction of the whole information in the data model is required we would always cut away a dominated branch and leave the dominating one. This is also visualized by having one branch continue straight while the other branch merges into the straight line. Therefore it is possible to follow with the eyes the dominant information. This visualization is inspired by the *prolongational reduction* in the music notation from Lerdahl and Jackendoff in chapter 5.2.

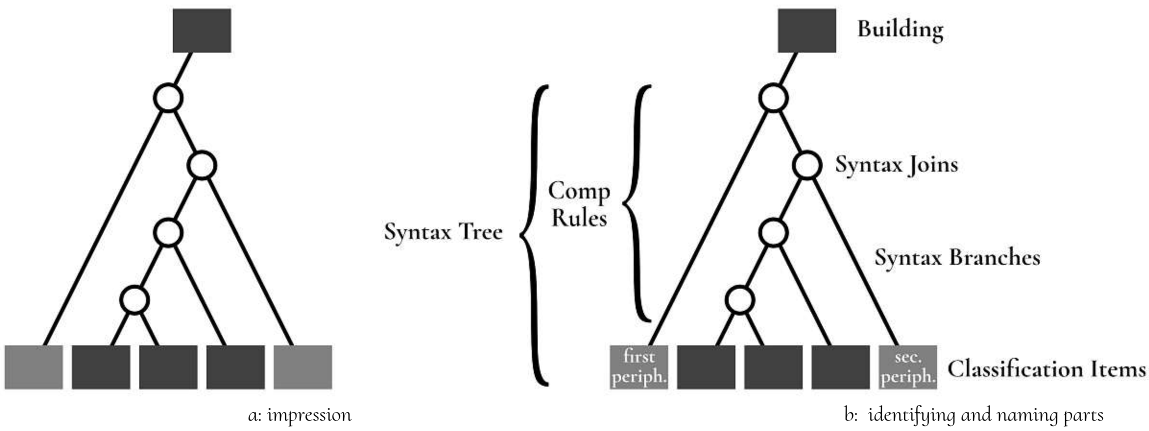


Figure 129: Visualisations of the binary tree data structure as used in this thesis. "first periph." is an abbreviation for "first Periphrase" and "sec. periph." for "second Periphrase". "Comp Rules" is a abbreviation for "Composition Rules"

Branches that are marked *significant* merge closer to the top into another axis then *normal* branches or branches that are explicitly marked as *minor*. In theory there is a more general rule at place: Even when all branches are normal their order in which they merge into another axis symbolizes their importance. The current software implementation is a bit more pragmatic and only enforces the "significant, normal, minor" sequence, but does not distinguish the finer grained merging points.

Periphrases which describe one distinct building part each, are always at the end of the main axes. 53 of the 80 World Exposition pavilions have a Syntax Tree. These 53 are augmented by classification items from up to three classification sets: *Spacing*, *Relative Size*, and *Variety*. Spacing itself can additionally be augmented by *Orientation* and *Cardinality*. Relative Size can additionally be augmented by *Size Randomness*. This order is not technically enforced but became a repeating pattern, because all data models were created by the same person. The software implementation is more generic and could handle and compare different orders.

Together the paragraphs in this section define a data structure custom tailored to describe building shape composition. It is named *Building Shape Syntax Tree*[91].

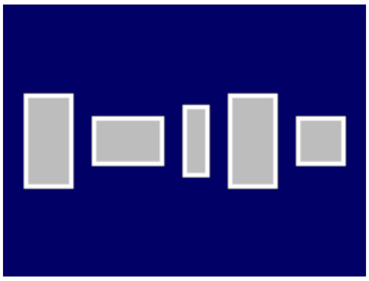
6.6.3. The Six Classification Sets

The following six classification sets are used in the Syntax Tree section to describe how two or more distinct building parts relate to each other. This relation can also be called the *composition* of distinct building parts.

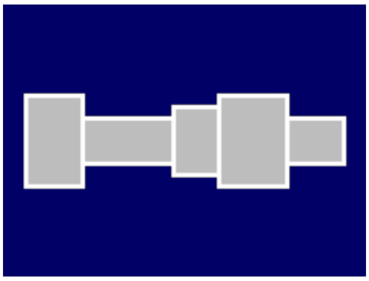
The following pages outline each of the six classification sets and showcases some prominent members together with associated photographs from real buildings. For a consistent and convenient overview each classification set starts on a new page. Exhausted definition and details are given in chapter 8.2.

91 For brevity we will call it Syntax Tree, as everything in these chapters is about Building Shape.

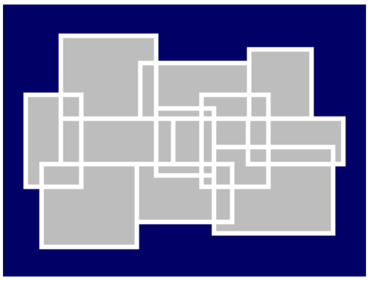
Spacing



a: spacingGapPartial



b: spacingContactPartial



c: spacingPlanarOverlapPartial

Figure 130: Three items from classification set Spacing

Figure 131: Applied spacingGapPartial

V3 - Expo 1967 Man the Explorer theme Pavilion (Montreal)

Figure 132: Applied spacingContactPartial

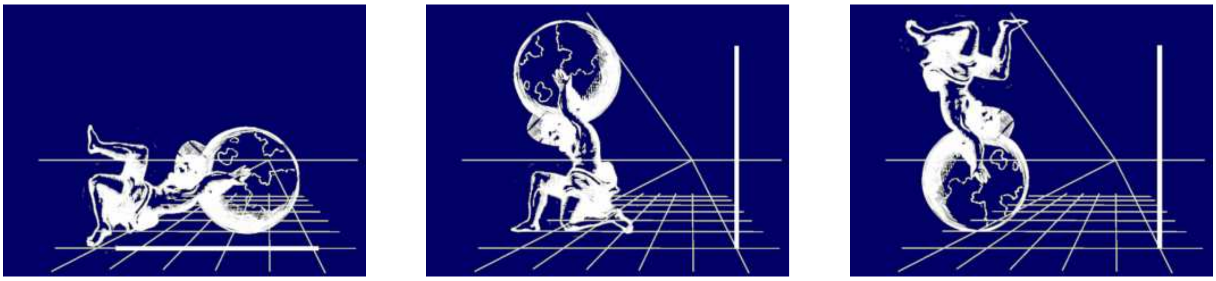
A7 - Expo 2010 Poland Pavilion (Shanghai)

Figure 133: Applied spacingPlanarOverlapPartial

X3 - Expo 1970 France Pavilion (Osaka)

Spacing (Figure 130) is part of linear or planar arrangement. The parts can have a gap between each other, contact each other at a common side, or overlap.

Orientation



a: orientationHorizontal b: orientationVerticalUp c: orientationVerticalDown

Figure 134: Three items from classification set Orientation

Figure 135: Applied orientationHorizontal

A7 - Expo 2010 Poland Pavilion (Shanghai)

Figure 136: Applied orientationVerticalUp

G7 - Expo 1970 Textiles Corporate Pavilion (Osaka)

Figure 137: Applied orientationVerticalDown

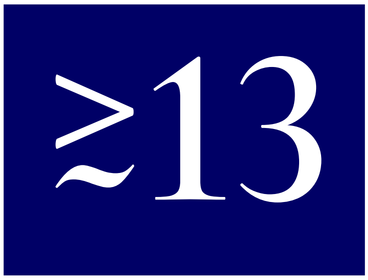
E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)

Orientation (Figure 134). Similar to the Periphrase there is no distinction between front, side and back. The most interesting member is orientationVerticalDown which is an upside down arrangement. Orientation usually augments Spacing.

Cardinality

a: card3

b: cardApproximatly5



c: cardApproximatly13OrMore

Figure 138: Three items from classification set Cardinality

Figure 139: Applied card3

V3 - Expo 1967 Man the Explorer Theme Pavilion (Montreal)

Figure 140: Applied cardApproximatly5

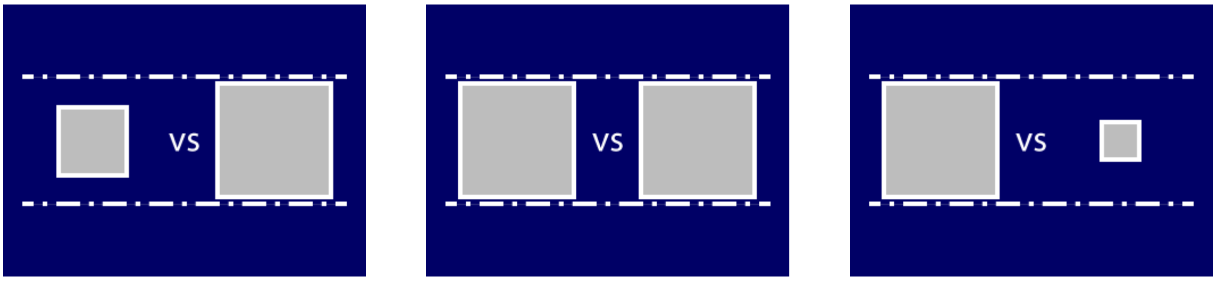
X1 - Expo 2010 Innovative Tours Theme Pavilion (Shanghai)

Figure 141: Applied cardApproximatly13OrMore

D3 - Expo 1967 Pulp and Paper Corporate Pavilion (Montreal)

Cardinality (Figure 138) is a mathematical term to refer to the number of elements in a set. Think of “1”, “2”, “3”. *Amount* or *count* are synonyms for cardinality. The classification set is used to identify the number of distinct building parts that are involved in the composition. Cardinality usually augments Spacing.

Relative Size



a: sizeLarger b: sizeApproximatelySame c: sizeSmallerSignificant

Figure 142: Three items from classification set Relative Size

Figure 143: Applied sizeLarger

B5 - Expo 2010 Luxembourg Pavilion (Shanghai)

Figure 144: Applied sizeApproximatelySame

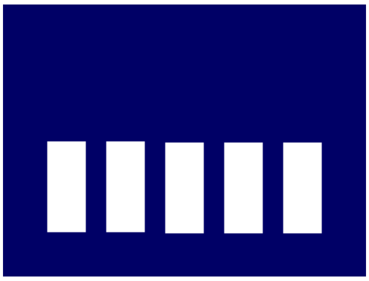
A7 - Expo 2010 Poland Pavilion (Shanghai)

Figure 145: Applied sizeSmallerSignificant

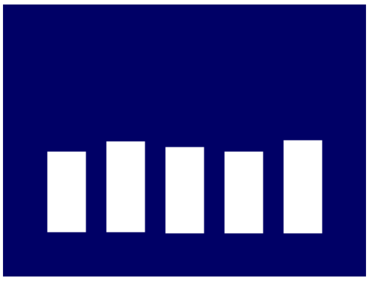
E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)

Relative Size (Figure 142) of the *dominated* distinct building part(s) to the *dominating* building part. As the architecture importance does not need to be bound to size it might very well be, that a small expressive distinct building part sits on a much bigger base which contributes less to the identity on the whole building.

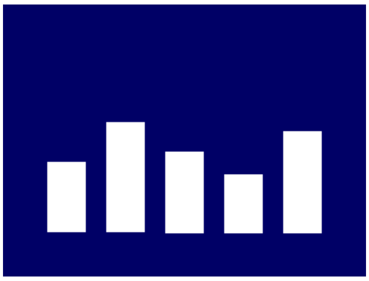
Size Randomness



a: randomNone



b: randomMinor



c: randomSome

Figure 146: Three items from classification set Size Randomness

Figure 147: Applied randomNone

V3 - Expo 1967 Man the Explorer Theme Pavilion (Montreal)

Figure 148: Applied randomMinor

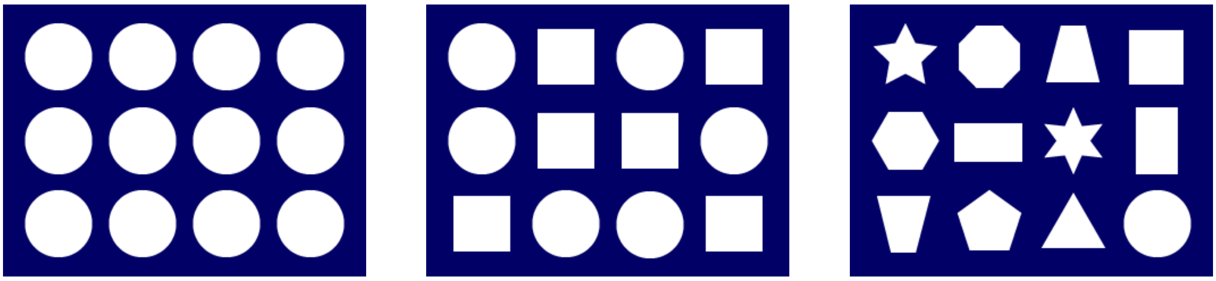
D7 - Expo 1970 Bulgaria Pavilion (Osaka)

Figure 149: Applied randomSome

D3 - Expo 1967 Pulp and Paper Corporate Pavilion (Montreal)

Size Randomness (Figure 146). When the Cardinality is equal or greater than 3, then we can also identify the Size Randomness of the Relative Size. For instance when a dominant distinct building part is surrounded by four smaller distinct building parts they might have none or maybe minor differences in relative size to the dominating one. Size Randomness usually augments Relative Size.

Variety



a: varietyNone b: varietySome c: varietyFull

Figure 150: Three items from classification set Variety

Figure 151: Applied varietyNone

X3 - Expo 1970 France Pavilion (Osaka)

Figure 152: Applied varietySome

A4 - Expo 2010 Russia Pavilion (Shanghai)

Figure 153: Applied varietyFull

D6 - Expo 2010 Netherlands Pavilion (Shanghai)

Variety (Figure 150) is related to Size Randomness and also applies when the Cardinality is equal or greater than 3. It is not concerned with size but rather with the uniformity or variance in the building shape. The building shape of distinct building parts can be related in their architecture style but still each one can look different. For instance the tower structures surrounding the A4 - Expo 2010 Russia Pavilion (Shanghai) in Figure 152.

6.6.4. Assigning Items

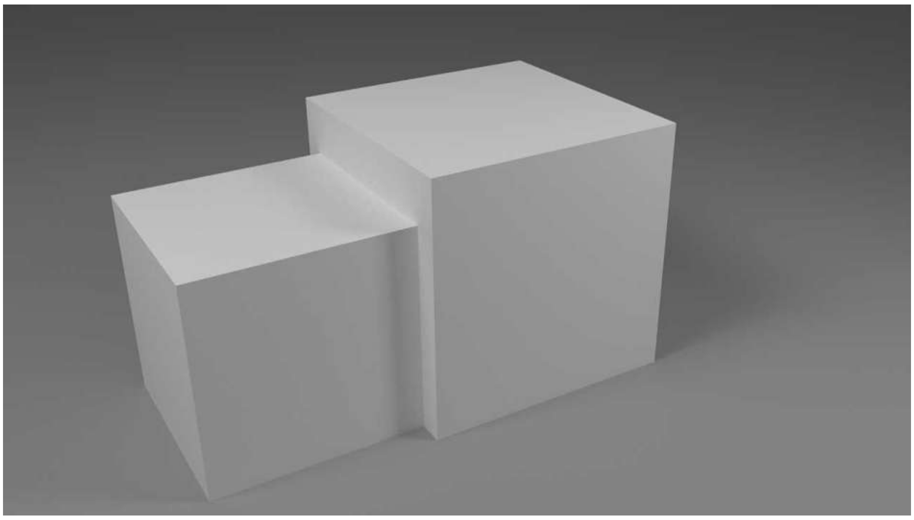


Figure 154: Visualisation of the Default Syntax Tree. A dominating distinct building part is accompanied by a second slightly smaller dominated distinct building parts. The two parts form one continuous building.

Similar to the assigning of classification items to a Periphrase the idea of "defaults to something" will also apply to Syntax Tree. Though it is not so easy to name it like in the Periphrase with "the perfect cube". Still the visualisation in Figure 154 should be easy to understand. Again the software will create a canonical representation and will fill in each missing slot with a default classification item. The default composition consists of two placeholders for Periphrases visualised as perfect cubes. We refer to it as *bigger part* and *smaller part*.

- The bigger part dominates the smaller part.
- The composition has a Spacing of *contact-partial*
- The Cardinality of the Spacing is *2*. (Cardinality augments Spacing)
- The Orientation is *horizontal* (Orientation augments Spacing)
- The Relative Size of the smaller part is *slightly smaller*
- Size Randomness is omitted, as there are only two parts
- Variety is omitted, as there are only two parts

Significance information is required in a Syntax Tree at the nodes where one axis merges into an other. The values are the same like in the Periphrase. The significance values *inferred* is used when default Syntax Tree are used. The value of *inferred* is close to the value of *normal.*[92] .Though an explicit Syntax Tree can also use *significant* or *minor*. Due to the nature of the branching binary tree an item like the *horizontal* orientation gets significance information three times:

92 For significance *values* see the introduction in chapter 7.2 and the *consequences for calculation* of rules chapter 9.7.3

- At the point it merges in the Spacing axis.
- At the point the Spacing axis merges into the smaller part Periphrase axis
- At the point the smaller part Periphrase axis merges into the bigger part Periphrase axis.

Syntax Trees can be bigger then the Default Syntax Tree, or the relative small Syntax Tree of the Kaleidoscope which follows next. Chapter 8.1 gives a first impression of Syntax Tree layouts in Figures 196, 197 and 198. Chapter 8.3 discusses the bigger Syntax Tree of A4 - Expo 2010 Russia Pavilion (Shanghai) and includes the modelling of self similarity. Appendix A (19.1) documents all Syntax Trees used in the empirical set up of this research.

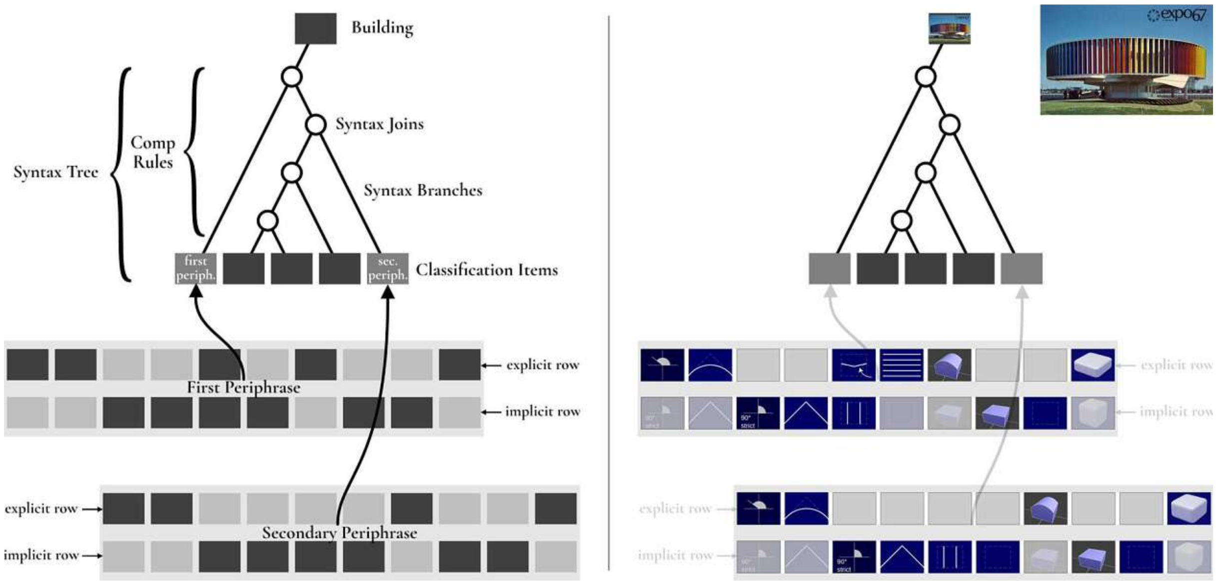
6.6.5. Syntax Tree Kaleidoscope Example

This section will use the Kaleidoscope as an applied example for the abstract Syntax Tree concepts above. Most explanations in this section are part of the captions of the Figures.

We can identify three building parts from photographs of the Kaleidoscope: The cylinder, a base below and a ramp. After analysis of the available photographs the visually light ramp is not considered a distinct building part and is dropped from the classification data. The cylinder is identified as the dominating distinct building part.[93] The base is of minor significance. One for the reasons to keep the base and not drop it, is the fact that it connects the cylinder to the ground.[94] The Orientation of the arrangement is orientationVerticalDown. This is seldom and marked significant.

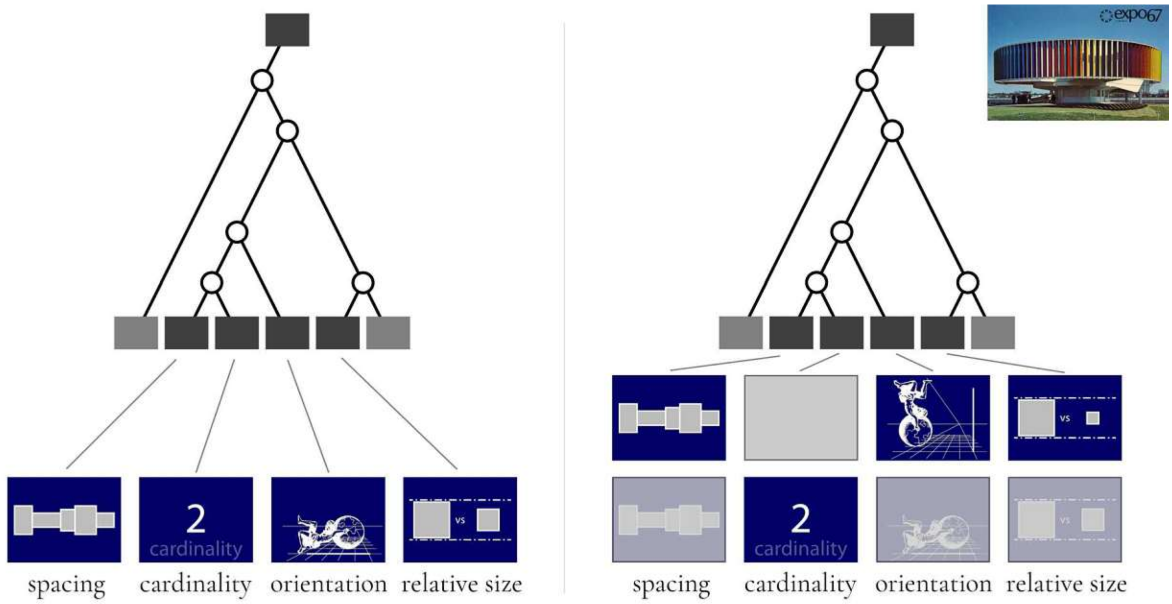
93 We lack some details about the Kaleidoscope because the building was created in 1967. Taking photographs was expensive compared with digital cameras available five decades later. We can assume that the architecture studio that did this design most likely took more photographs, and maybe the owners as well. The public concentrates on the colourful cylinder. All but one found photographs of the building in the Internet and the digital archive of the city of Montréal, show the cylinder. It can be assumed that the cylinder is important and the base and the ramp are secondary. The fact that parts of the cylinder are hollow are considered secondary.

94 At the end of the thesis we will explore the consequence of dropping the base in 12.4.2 and Figure 344.



a: abstract diagram b: applied diagram

Figure 155: The abstract and the applied version of the diagram that introduces the proposed classification system of this thesis. We can see how the Periphrase of the cylinder is reduced to one leaf on the left end of the Syntax Tree and the Periphrase of the base is reduced to one leaf at the right end of the Syntax Tree.
A full page version of the astract diagram is available in Figure 60



a: collapse row b: two rows

Figure 156: In the previous Figure we see an implicit and a explicit row for each of the two Periphrases. The same is also valid for the classification items of the Syntax Tree. On the right we see a collapse row where all items are reduced to a single row. On the right we can see a visualisation similar to the Periphrase. We can see that the Cardinality is actually an implicit default item, While Spacing, Orientation and the Relative Size items are explicit. We will see that the following Figure will use a faded grey to visualise default items. We can also observe that the explicit Spacing is actually the same as the implicit Spacing. So the person creating the classification decided to make it explicit. Making it explicit will give it a slight advantage with the rules in chapter 9.7.3. It might also make documentation and discussion easier as it states the explicit decision.

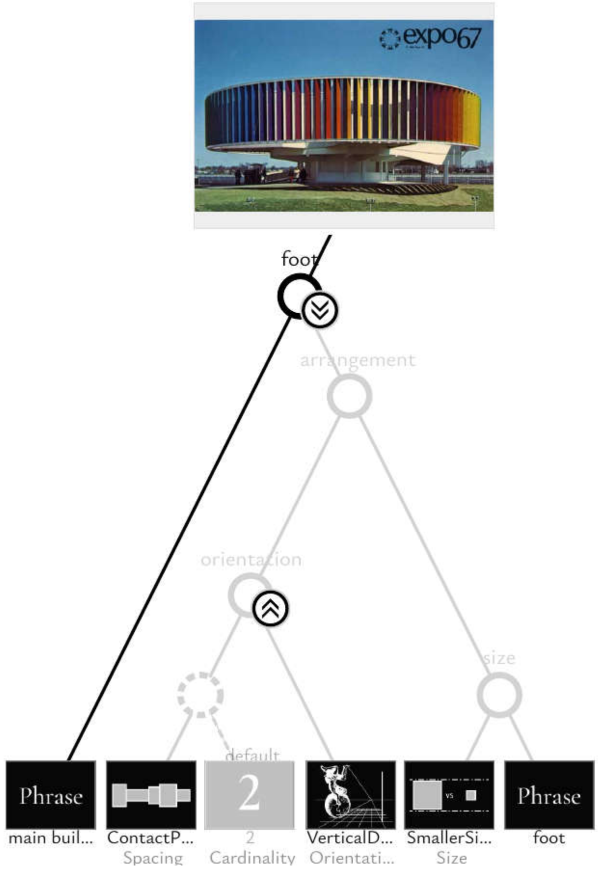


Figure 157: E3 - Expo 1967 Kaleidoscope Pavilion (Montreal) as it appears in Appendix A (with bigger photo). The default item of cardinality2 is rendered in a light grey and with dashed lines. The circle with the two upwards arrows indicate the significant orientation. The two downwards arrows indicate that the whole second Periphrase of the base is consider of minor significance once it is dominated by the main distinct building part: the cylinder. The minor significance of the whole branch is also rendered as grey lines of the tree diagram itself.

The observation that the cylinder is actually cantilever is therefore modelled in two "competing" places. On the one hand the Periphrase of the cylinder has a Tilt classification item of tiltViewFromBelow. On the other hand the combination of a Relative Size item of sizeSmallerSignificant and the seldom and significant Orientation of orientationVerticalDown tries to carry similar information. It is not uncommon that classification sets have overlaps, though this is one of the few instances were an observation is modelled as a classification item in the Periphrase, as well as a pattern in the Syntax Tree. It is present on both sides of the interface between the two concepts.[95]

This cantilever observation is actually one of the new insights of the research project. A future end user facing application might allow to query for "significant cantilever objects". This might expose previously unknown connections. One might argue that this is not only of interest for inspiration in the design process but also for problem solving like construction details within bigger corporate archives.

95 See also last paragraph of 7.3.3.

7. Building Shape Periphrase

Chapter 4.2 tells the anecdotal journey that resulted in the concept of *Building Shape Periphrase*[96]. Chapter 6.5 gave an initial overview of the concept. This chapter adds background information and also incudes an exhaustive enumeration of all classification sets and their containing classification items which are used within a Periphrase. The term *Periphrase* is borrowed from language science but is used in this thesis to describe the concept described in this chapter.

At the beginning of this research the assumption was to organize Building Shape classification items in a *hierarchical binary tree* all the way throughout the proposed system. This was driven by the idea to transfer some academic concepts from cognitive linguistics to architecture. Language science uses binary trees as an analytical, computation and visualization tool to expose the syntax of natural language sentences.

The use of binary trees at the composition level of Building Shape is very visual. The use of binary trees is an important part of this thesis and will be further discussed in chapter 8 when we focus on Syntax Trees. In chapter 8.4 we will see that the use of binary trees can theoretically be expanded to the Periphrase as well. But a simpler linear visualisation makes the Periphrase more accessible.

We revisit the linguistic terminology:

- *Sentences* are made of smaller parts like *phrases* and *words.*
- *Phrases* are made of *words.*
- *Words* are made of *syllables* and *letters.*
- *Syllables* are made of *letters.*
- *Words* are retrieved from a *lexicon*[97]

We can draw a parallel that Building Shape Syntax Trees are closer to sentences and phrases and Building Shape Periphrases are closer to phrases and words. We can see that in the preceding sentence, both concepts claim a connection to linguistic phrases. This exposes the difficulties to transfer concepts between domains. It also hints that there are some similar rules in place in Syntax Tree and Periphrase. The connection between Periphrase and the linguistic term *word* hints that a Periphrase is a more encapsulated

96 We will mostly refer to *Building Shape Periphrase* just as *Periphrase* in this and the remaining chapters. As there is less ambiguity then in the interdisciplinary chapter 5.

97 Jackendoff even argues that the lexicon can carry phrases themselves like “kick the bucket”. Therefore the small phrase becomes a essential building block. See also chapter 8.4

entity. In linguistics science we can investigate structure of sentences and phrases independent from the structure of words.

The Word "Periphrase"

The author of this thesis is not an English native speaker, so the choice of the term *Building Shape Periphrase* might not be ideal, but there was a need for a term to group some classification items. A German thesaurus usually contains the term "Periphrase"[98], even though it is mainly used in language science and hardly used in everyday speech. The most appropriate English translation in our context is "Circumlocution".

In this thesis *Periphrase* is used exclusively to describe a certain type and setup of Building Shape classification items and not in its German linguistic meaning[99]. The real German word Periphrase seems well fitting because its two parts already fit. The Greek rooted part "peri" translates to "around". "Peri" hints that we want to express or describe one thing with other things, especially by avoiding the use of direct words. The part "phrase" describes in linguistics a group of words that function together and this research is inspired by cognitive linguistics.

7.1. Context - Gravity and Cultural Constrains

Why is there a need for special Building Shape classification sets, and why not simply use the IL 22 work? The IL 22 system is intensionally very open and does not require any scale. As quoted before it does not require a use case like architecture. It is a system that tries to describe organic nature as well as human made objects in a consistent way. The building shape classification sets inherit a lot of ideas and vocabulary from IL 22 but are more constraint. The additional constrains are rooted in the following assumptions:

- **Human Scale –** The human scale and the scale of a World Exposition pavilion are in relation to each other. There are no buildings that are smaller then a human and the largest investigated pavilion; the Chinese host Pavilion on the Expo 2010 in Shanghai; is still within a scale that a human can handle. Of course this pavilion has a special building shape, but it looks like a tall approximately 20 stories building and an observer can identify different floors, windows and entries.

98 A crisp German definition is "Umschreibung eines Begriffs durch eine kennzeichnende Eigenschaft" Duden (the leading German dictionary http://www.duden.de/rechtschreibung/Periphrase , accessed 2017)

99 The alternative to a borrowing of the term Periphrase would be to invent a new word or use an abbreviation. Borrowing words from other domains is common in a living language and in science. For instance the term "architecture" which originates in building science has a different – but related – meaning in computer science and software engineering.

- **Gravitation** – Humans have an equilibrium sense and the 90 degree angle can be connected to perpendicular forces of gravitation.[100] [101] We have a biological sense of what an upright objects is. Humans can feel with their equilibrium sense that they are standing on a slope and to some degree they can infer that an object they are observing is not upright by comparing their current visual information with their current equilibrium sense information. When being on location, it is also easier for humans to detect that a building has a leaning wall of 85 degree then to detect that a ground plane or a corner is off by the same amount. Of course it is possible for architects to trick our senses but then this is an intentional design decision.

- **Indirect Gravitation Effects** – Humans are not only able to sense gravitation but they have also learned that gravitation is an important constraint to our building culture. We can look at photographs of buildings and infer that they are, or are not, upright. We know that a typical photograph is a documentation of a real world building and by connecting secondary information like a person, a road, a horizon line, a tree, or a street sign we can build up a context. This kind of context helps to determine if a building part is upright.[102] The photographer that took the picture can trick us by using some lens distortion, holding the camera at a certain angle or leaving out any context objects, but again these are deliberate design decisions of an artist. In these cases we can assume that the main intention of the photographer was not to objectively document a building shape but rather emphasise something subjectively. Our visual senses are tailored to deal with day to day obvious information and not illusions.[103]

- **Cultural Gravitation Effects**[104] – As humans we are surrounded by buildings and we see repeating patterns. For example upright walls seem to be economically efficient to create a maximum of internal usable space. A tilted roof works well to guide rain water. It is the role of academic research to argue that these might not be the most efficient

100 On a global scale the perpendicular axis is not a perfect 90 degree angle as it is influenced by the elliptical shape of the globe. But on a human scale, like the one used here for buildings, this approximation is widely acceptable.

101 For more gravitation related insights about Tilt see also chapter 7.3.3.

102 When we read into Pizlo's approach with the special role of symmetry and "a priori constraints" we can see how effective the gravitation information can become: "We, and our model, needed to have the following knowledge about the world (1) the direction of gravity, (2) that objects tend to stand on a relatively large planar (flat) surface (a "floor") that is often orthogonal (at 90°) to the direction of gravity, (3) that objects are symmetrical, (4) that their plane of symmetry is parallel to gravity, and (5) that objects have approximately vertical legs and/or surfaces. Using these 5 characteristics (constraints) we are able to: (a) detect the ground plane and vertical walls. [...] (b) compute the horizon [...] (c) identify the vanishing point [...] (d) estimate the 3D position [...] of the symmetry plane" *et al.*, 2014, p. 137). Five more inferences with the letters (e), (f), (g), (h) and (i) follow. For more discussion about Pizlo's use of symmetry see chapter 8.4.

103 In Vision: "The traditional way of dealing with this problem is to assume the existence of environmental constraints to restrict the set of possible interpretations. " (Pizlo *et al.*, 2014, p. 2).

104 We often refer to Pizlo's a priori constraints. These constraints are assumed to be innate and stable. Stable in a sense that they do not change over a period of time like decades. We list various effects in our text. While human scale and gravitation effect might qualify as such, the cultural effects do not. Culture is slowly evolving and is not necessary stable over time spans like decades.

patterns to enclose space[105] but when we look at a picture of a typical city we see that these patterns are dominating. Maybe this is due to economical aspects rather then technical aspects. There is also a flip side of this recognition of patterns: When a building; or a distinct building part of it; does not conform to the typical assumptions then we tend to recognize this. For instance we are more used to the observation that buildings get narrower the higher they are, then to the opposite. Vertically widening or even horizontally cantilever buildings are seldom and we recognize this. This has more to do with the statistical chance to encounter such a building then with technology or nature. It is structurally possible to build and the laws of physics allow to erect these kind of buildings within their rules.[106]

- Further Cultural Effects – The previous paragraphs were bound to the nature effect of gravitation mixed with human building culture. But there are further typical building patterns that seem to be grounded in culture and technology rather then nature effects. Rectangular ground planes seem to be economically efficient to sketch, arrange, communicate and construct. Rectangular angles are seldom in nature but are common in man made objects. The Cartesian coordinate system is taught in schools and is common knowledge. The Cartesian coordinate system is of course deeply routed in mathematical logic.[107]

So we are used to rectangular building ground planes and the same flip side effect can be assumed. When we see a building that has a different ground plane which is not rectangular we are more likely to recognize it. Again this has more to do with the statistical chance to encounter such a building then with the geometric properties themself.

But in contrast to the human equilibrium sense, we don't have a biological sense for a rectangular ground plane. It is a cultural norm. We also know that there is something like a *perspective depth and foreshortening* when we represent a three dimensional object on a two dimensional media. In the context of buildings there is also the issue of human scale. When being at a building site it is hard for a human observer to judge if two walls touch each other at an exact 90 degree angle. We assume that they are because it is often the cultural norm for buildings to have a rectangular ground plane. But we can not be as confident about it like with the upright walls. It seems that we are also more tolerant in real world architecture then in geometry science what a *perceived* 90 degree angle is. We

105 For instance the publication group "form <-> force <-> mass" IL 21 (Basics), IL 22 (Form), IL 23 (Structures), IL 24 (Lightweight Principle), IL 25 (Experiments) from the institute for Lightweight Structures, University of Stuttgart. Institut für Leichte Flächentragwerke; see also chapter 5.4.2.

106 Our canonical example, the Kaleidoscope and its curated group *cantilever* are examples of this.

107 One possible connection to building shape might be that the perpendicular axis, which is defined by nature due to gravitation, creates a plane once we define a direction for the second dimension. In an architectural context this is often the imaginary view plane that is parallel to the observers. When we apply the same idea of a perpendicular axis onto the view plane, we get a ground plane that follows the same rules. It is now technically convenient to deal with such a coordinate system, because there are many common notions and axioms to follow.

might tolerate 88, 89, 91, 92 degree angles in a ground plane as de facto 90 degree angles. We are tolerant in the built environment to these deviations when they do only within small limits influence other aspects like economical performance or usability. When we look at city maps of densely populated urban areas that grew organically rather then straight from a drawing table we see many slightly off 90 degree angle that sum up to typical urban patterns. At human scale as a person standing at a street corner we hardly recognize the difference between an 85 and a 95 degree corner.

To summarize: Human scale, the limits of human perception of large objects, perpendicular axis due to gravitation and human building culture are the additional constrains that differentiate the building shape classification described in this thesis from the IL 22 work.

7.2. Context - Perfect Cube

The presence of the constrains enumerated in the previous chapter is a good thing as well. The constraints allow to have a reduced classification system and a lot of properties can be thought of as default behaviour.

In a lively conversation humans can exchange information. According to linguistics the way we create sentences to communicate in a language like English is driven by recursive optimizations. But in a face to face conversation the sentence does not stand by itself.[108]

- *Syntax* – We construct the sentence according to the rules of the language we negotiated with our conversation partner. We usually want to express the message in as few elements as possible.
- *Lexicon* – We choose from our in-memory lexicon of available words the subset which we assume that our conversation partner does understand.
- *Common Ground* – We assume a common ground on the topic. This might have been established just a few seconds ago, in the previous sentences, or years ago in school curriculum.
- *Vocal Intonation* – We can use vocal stress to emphasise certain parts of the sentence.
- *Semantic* – Our conversation partner will use his semantic capability to help to decode the message in areas where the linguistic information is to optimized, ambiguous or novel.

108 The following is a simplified view on language science. The list is not exhausted but only enumerates concepts that have a counter part in Building Shape Classification. It should also be noted, that this kind of knowledge transfer is not uncommon. For instance computer science also uses terms that originate in language science and adapt them for its specific use. We could also argue that the six items that the author reuses originate from computer science with terms like syntax, keywords, axioms, links, weights and visualisation. It just happens that the theme of this thesis is a knowledge transfer from linguistics.

- *Gesture* – We can use hand and facial gestures to support the message that we want to transport.

In a dry technical setup as persons with the task to classify a building shape on a computer we are more limited but still follow many of these patterns:

Syntax becomes technical syntax

The cognitive capabilities of a computer software system as it was implemented for this research in 2021 is still not at the level of a human.[109]

But computers are good at following technical syntax that obeys logical rules. We as humans usually agree to reduce our syntax to the one understood by the machine to get our task done. The computer user interface would typically enforce the limited syntax by not allowing inputs that break the rules. Often the human must first learn what this reduced new syntax is, similar to the way one can learn a new natural language. The rules for Building Shape classification in the two main parts *(Building Shape) Periphrases* and *(Building Shape) Syntax Trees* are few but still need to be understand beforehand.

Lexicon becomes the sum of all items in the various classification sets.

A lexicon holds all the items that can be used within the technical syntax. This chapter introduces ten classification sets and the following chapter introduces six classification sets. By having the classification items grouped in sets they are easier to understand. Semantic relationships within a classification set is less surprising. The items in the Building Shape lexicon are not necessary words. They are abstract concepts and can therefore also be represented in sketches and renderings. There is no need that the classification items are all expressed perfectly and without ambiguity in English words. The thing we want to classify is a potentially complex Building Shape. This shape does not necessary have a designated name for itself. Shape is a visual property and text is only a carrier of information. For instance, we will see that the *Curvature* items are easier to understand as sketches then with their correct scientific terms. Also the *Proportion* items are very hard to express in English words but the visual matrix is easy to select from. Some items are abstract, like the members of the *Lattice* classification set. Still, in the technical implementation there will be a text representation of all items. This is mainly due to the limitation of traditional software that requires unique text identifiers to store and retrieve the information efficiently.

109 Of course we see substantial progress in computer science in the current years. But in the applied field of software development most of our day to day tasks are still performed with simple user interfaces, text-based editors and form based inputs.

Common ground[110] becomes the default items

In a conversation we are often leaving out the obvious information that we take for granted and focus on the properties that are important for the identity of the subject. We do this for the sake of efficiency. When we try to describe a third person to our conversation partner we would most likely not start with the information that this person had two legs (see *significance* further below). We would focus on the identity defining properties like the sex, age, height or hair colour. By leaving out the information about the hair colour we implicitly carry the information that it is not so important. Our conversation partner would be surprised that we did not start from the beginning with the information: "the woman with the ginger hair".[111]

Our conversation partner will put some default values to all other properties that we did not explicitly mentioned. When the context is a university cafeteria then the default age would be maybe 21 and if the context would be a home for the elderly the default age would be much higher.

The context for the Building Shape classification in this thesis are 80 World Exposition pavilions. They are constructed in between 1958 on the Expo Brussels and 2012 on the Expo Yeosu. Architecture in this time period and for these kind of buildings defaults to different properties then for instance the Building Shape of cathedrals in the middle ages.

Therefore one deliberate decision in this thesis is the assumption: When we are leaving out information about the Building Shape of World Exposition pavilion we are defaulting back to the properties that would describe a *perfect cube* like in Figure 158.[112]

110 Synonyms for "common ground" are "common knowledge", "mutual knowledge"
see chapter 2 of Allan, Keith. (2012). What is Common Ground?. Perspectives on linguistic pragmatics. 2. 10.1007/978-3-319-01014-4_11.
The term "joint believe" is also a synonym.

111 There are cultural norms and taboos. This information differs from culture to culture. We would most likely start with the information, if the person is a male or female, even though this information might only cut the data set in half.

112 When we iterate over the four a priori constraint: 3-D symmetry, planarity, maximum 3-D compactness, and minimum surface (Pizlo *et al.*, 2014, p. 71). We can infer that a sphere and a cube are competing for the poster child position. While the sphere is at maximum 3-D compactness and minimum surface, it is missing the planarity. "a sphere is the maximally compact 3D object, and a cube is the maximally compact object built from 3 pairs of parallel quadrilaterals." (Pizlo *et al.*, 2014, p. 64). The cube is also serving the planarity a priori constraint. A synonym for planarity is flatness. The choice for the cube over the sphere is also supported by the rectangularity constraint which is attributed to Perkins (1972) by Pizlo: "Perkins showed that the human visual system knows the rules of orthographic projection [...] Perkins suggested that the rectangularity constraint is similar to the Gestalt psychologists' simplicity principle" (Pizlo, 2008, p. 70).

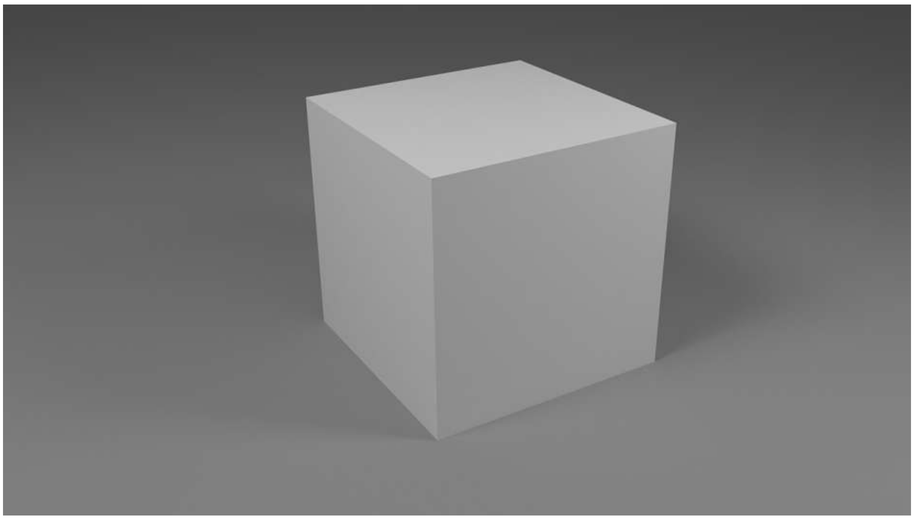


Figure 158: "Perfect Cube"

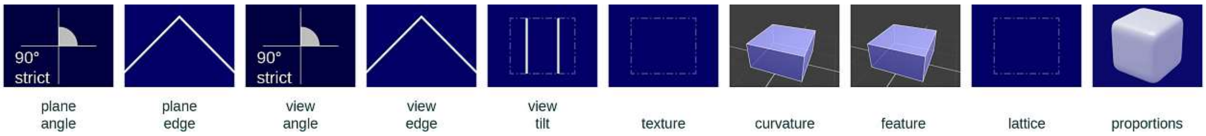


Figure 159: The ten classification sets with their default items that help to describe the "perfect cube"

We can see the sketches of the ten classification items in Figure 159. Their technical keywords are as following:

- Angle-Plane: anglePerpendicularStrict
- Edge-Plane: edgeSharp
- Angle-View: anglePerpendicularStrict
- Edge-View: edgeSharp
- Tilt: tiltApproximatelyNone
- Texture: textureSmooth
- Curvature: curvaturePlanar
- Feature: featureNoSignificant
- Lattice: latticeNoSignificant
- Proportions: proportionZeroZeroZero

Common ground becomes the multi-assignment

A second consequence of common ground is that we have a deal with the software system. It promises us that we are not required to provide a full, potentially time consuming, digital 3D model in the data input stage. We have to follow the syntax rules, though it only requires classification items that are like tags or keywords in an index. So we as humans decide what is important and how to; if at all; break up the World Exposition pavilion into smaller parts. Because the set of items in the lexicon is very limited but still should potentially be able to describe very complex buildings shapes we need flexibility. One of the flexibilities is that the classification items are not exclusive from within a set. And even contradicting items can be assigned on the same distinct building part.

Figure 160: F3 - Expo 2000 Japan Pavilion (Hannover)

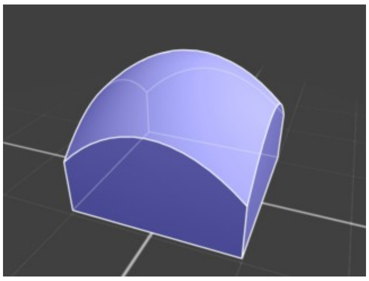


Figure 161: synclastic curvature, curvatureConvexConvex

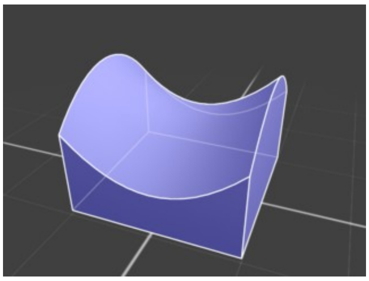


Figure 162: anticlastic curvature, curvatureConcaveConvex

For instance the Curvature classification set has a classification item convex+convex (synclastic) (Figure 161) and one for convex+concave (anticlastic) (Figure 162). F3 - Expo 2000 Japan Pavilion (Hannover) (Figure 160) has a building shape with both properties. It seems unreasonable to request to slice the building shape into distinct building parts exactly at the lines where they are changing curvature direction. So we must be allowed to assign both synclastic and anticlastic items onto this building. There is also a third curvature property in the building. The both ends of the vault like structure are planar. We might argue that these walls are important then we would add a third item from the Curvature classification set into the description of the building. We might also argue that they are not important for the identity and omit the planar walls completely.

Intonation becomes the significance attribute

Going back to the example where we try to describe a third person to our conversation partner. If due to an accident the person might have lost one leg this would become a property that distinguishes this person from a vast amount of the population in a normal context. We would usually start with this property and even stress the importance. In a written language we can do this by adding an adverb like “only”. In vocal language we have an addition tool: the voice and additionally adjust vocal intonation. Another example would be a *very* tall man. In building shape classification we can do a similar thing by applying the *significance* attribute. It can have four values:

- *significant* – we assign this attribute to emphasise something important or rare.
- *normal* – it can be omitted and the software will add the attribute *normal* if no other value is present.
- *inferred* – when values are added by the software because of the previously discussed assumption of the default perfect cube then these are marked up as *inferred*. This is

different to *normal* and will cause a penalty in similarity calculation. The rational is that if a person doing the classification mention an item as *normal* some effort was invested so the information must be of more value than a purely inferred value. If we start to explicitly describe a perfect cube by pointing out each property it must be more that the assumed default values that hint implicitly towards a perfect cube.

- *minor* – this allows to rate a certain property down. It might have been observed and the effort to document it “for completeness sake” has already been done but one decided that it is actually not so important. In chapter 12.4.2 we will be able to see the effect of leaving the minor items out, so we can judge if they influence the results and are worth the effort.

Due to the aforementioned flexibility there is even no need that the significance attribute is exclusive within a slot. For instance the Japan pavilion has a significant curvatureConvexConvex (synclastic) and a significant curvatureConcaveConvex (anticlastic) Curvature. This is because the curvature seems to be the most important identity driving aspect.

A second place where we need flexibility for multi-assignment is more hidden. When we would state without any previous sentence: “The cathedral is stretched” we would still assume that the cathedral is high. Because an idealised stereotype of a cathedral has tall towers. In spoken language this can be hinted to the conversation partner by adverbs like *also*. The software implementation of this feature is called *behaviour* and can have the following attributes:

- *override* – Which is the default. When we apply a Curvature of curvatureConvexConvex to our building shape description, we can *override* the information of a curvaturePlanar that comes from the default values that describe a perfect cube. As a result, there is only one active Curvature classification item.

- *add* - When we apply a Curvature of curvatureConvexConvex to our building shape description, we can chose to add it to the information of a curvaturePlanar that comes from the default values that describe a perfect cube. There are now two active Curvature classification items. We might do this because we think that the planar ends of the vault should also be mentioned and this is a very efficient way to preserve the information.[113]

Semantics becomes the weighted relationships

As of 2021 semantics, as a cognitive theoretical research fields, as well as practical computer science implementation effort, is still a very evolving topic. The human capacity for semantics is impressive and a simple project like Building Shape classi-

113 In spoken language we might use the term “also”, like in “It’s *also* curved”. Not used in an enumeration, the term *also* implies that there is an unspoken default that is not overridden.

fication can only pick some very simple low level concepts that originate from there. First the items in the lexicon are grouped into sets that makes it easier to reason about. The second adoption is that items do not exists in a vacuum but are connected to each other. The approach is similar to synonyms in a thesaurus.

Gesture becomes aerial

The analogy that hand and facial gestures can support aural information becomes the aerial and satellite photographs in Building Shape classification is a bit stretched. But it might show that even when we talk about language there are things that are only indirectly related that can still help to carry information in a spoken conversation. In language science this is the role of Pragmatics.

The importance of the human scale and the limitations of perceptions have been mentioned earlier. Therefore one might argue that we should only use photographs that are made from a pedestrian eye level. This concern is theoretically valid but it is not practical for some reasons:

- Ideally we would not use photographs at all but speak with visitors of the World Expositions of Brussels 1954 up to Yeosu 2012 on site and give them the task to concentrate at Building Shapes rather then enjoying the exhibitions.[114] This is not feasible in retrospective and even in the future this would be a challenging task. To allow research efforts in architecture like this one we rely on photographs or other media.
- Access to pedestrian level photographs that show a building shape is limited for pavilion that are not *famous*. Finding pictures of the back side of a pavilion is usually luck. The photographs taken by professional architecture photographers are often subjective. The same is true with architecture renderings that are usually produced for marketing purposes and emphasise on the most positive details.
- Photographs are 2D captures of monocular 3D information. Humans have a binocular vision to understand 3D space. With their two eyes they have *two camera* all the time: a three-dimensional projective space[115]. Humans can readjust their view point position, for example by moving one step to the left to get more stereoscopic

114 Britannica summarises all senses of a *unified perceptual experience* as: vision with binocular disparity supported by the spatial cue vestibular stimuli (sense of balance) and additional cues from auditory (sense of hearing), kinesthetic (sense of bodily movement), olfactory (sense of smell), gustatory (sense of taste) experience. Though the Encyclopedia points out “Despite all this sensory input, most individuals receive the bulk of the information about their environment through the sense of sight, while balance or equilibrium (vestibular sense) apparently ranks next in importance.“
Järvinen, E. Jaakko , Fieandt, Kai V.J. von , West, Louis Jolyon and Korkala, Pekka Yrjö. "space perception". Encyclopedia Britannica, https://www.britannica.com/science/space-perception. Accessed 30 October 2021.

115 See (Koenderink *et al.*, 2010, p. 41)

information and complete a picture in their head. Though still a niche[116], stereoscopic photography is technically feasible in 2021 but there are no known sources based on photography available for the old World Expositions.

- In 2021 there are consumer technologies like Google Street View which would allow to do a pedestrian level only approach, but this data can not be created easily in retrospective.[117] No such visual data set is accessible for the relevant World Expositions of Brussels 1958 up to Yeosu 2012. Even World Exposition 2015 in Milano does not have this data at Googles web site.
- If the Google Street View data would be available it has different usability characteristics. Technology savvy people don't have a problem in using such technologies but it takes longer to navigate through it. The technology must use interpolations to compensate lens distortions. Also the current emergence of consumer grade Virtual Reality head sets would not help, because for Street View like photographs they have the same limitations. Head sets work best with real 3D data that is also expensive to create in retrospective.

Due to the above limitations the solution is quite pragmatic: The use of satellite images and aerial photographs fills the gap. We rely on the cultural competence that we as humans have to combine the pedestrian level photography and the aerial images in our head to *see* one Building Shape. The aerial photographs compensate to some degree for the missing stereoscopic information. They allow to walk around the building within moments in our mind.

We also get some support from Vision research. We repeated several times that there is consensus in the field that metric/quantitative perception is error prone. Though some studies (Lee *et al.*, 2012) hint that large perspective changes of more then 45 degrees might be a pattern to improve metric/quantitative perception. These kind of large perspective changes can be achieved not only by additional photographs from the pedestrian point of view but also by aerial and satellite photographs.

For the empirical data gathering later in this thesis the main task of the participants was to compare two building shapes. This was done by simply showing photographs side by side. Having an immersive Google Street View setup or Virtual Reality head set approach would make this harder. The participant where able to compare 352 pairs of buildings

116 Research efforts that might lead to consumer grade devices could enable interesting application within architecture research projects. One example is Google's Project Tango/ARCore.

117 Microsoft's retired Photosync research project is a counter example. But for their technical approach one needs big amounts of photographs which are only available for few popular places in the world. https://en.wikipedia.org/wiki/Photosynth
Snavely, N., Seitz, S.M. & Szeliski, R. Modeling the World from Internet Photo Collections. *Int J Comput Vis* **80**, 189–210 (2008). https://doi.org/10.1007/s11263-007-0107-3

within approximately one hour. Chapter 11.1 elaborates on the use of photography in architecture research.

Later, in the Syntax Tree example of the following chapter in section 8.3.2 we will also see "Expansion and Reduction" of the Periphrase information of the A4 - Expo 2010 Russia Pavilion (Shanghai).

This chapter will continue with a detailed view of the ten classification sets. They are present in all Periphrases either explicit or implicit. When completely left implicit their default values define the perfect cube. The theoretical opposite of the perfect cube though would not be a perfect sphere, but rather a very complex, most likely impossible, building with all classification items applied at once. Some kind of faceted, spiky, twisted and stretched blob.

7.3. Periphrase Classification Sets

Grouping of entities under umbrella terms is common.[118] We call our groupings *classification sets*. The entities in these classification sets are called classification items. Ideally these classification items are foundational. Though they have been composed before the first empirical evaluation which happens in chapters 11 and 12. Further external evaluations would be ideal. Each evaluation could add incremental improvements.

Each distinct building part is attributed with at least ten classification items from ten classification sets. Therefore we can describe these as ten *slots*, for instance the *Tilt slot*. It is possible to assign more then one classification item from the same classification set in one slot. While we introduce each classification set in isolation, we should remember that in an applied example they appear together. Also classification sets are related and might have an overlap.[119] . We might also recall that we even have redundancies crossing conceptual layers like the Syntax Tree and the Periphrase.[120] These redundancies are accepted in analogy to the redundancies in Vision for depth cues, or the linguistic approaches by Jackendoff and Culicover.[121]

---

118 For instance researchers of Semantics, group their formation rules like: Thing (or Object), Event, State, Action, Place, Path, Property, and Amount (Jackendoff, 2010, p. 10).

119 For instance the Angle-View and Tilt classification set. Or the *obtuse angle* and the *smooth edge*.

120 For instance in cantilever buildings like the Kaleidoscope: the Periphrase item tiltViewFromBelow item versus a combination of a Relative Size item of sizeSmallerSignificant and the seldom and significant Orientation of orientationVerticalDown; see also chapter *6.6.5*.

121 Jackendoff and Culicover had to make a very strong case in their competitive research domain of language science ,why redundancies are acceptable to defend themself against the main stream view of the Minimal Program, which tries to eliminate nearly all redundancies. (Culicover and Jackendoff, 2005, pp. 541, 543)

The Angle, Edge and Tilt classification sets are present in two orientations: *plane-orientation* and *view-orientation*. *Plane* refers to the ground plane, while *view* refers to any view like front view, back view, side view. The Periphrase contains an "Angle-View" slot and an "Angle-Plane" slot. The items are the same and are therefore discussed together.

All classifications sets have relationships between many of their items. These relationships are documented in Appendix B (19.2). The relationships are used in the rules that use *Weak References* 9.3.

7.3.1. Angle (Plane- and View-Orientation)

The term *angle* is mostly known from geometry where it is used as a precise measure. Precision is also required during the construction phase of buildings. But for most buildings even the precision on construction sites is not as strict as the geometric one. Small errors are tolerated and taken into account from the beginning.

While angles can be represented by a simple and precise mathematical degree number, they are less simple when it comes to perception. For instance "There is no meaningful way of defining the angles around and within the body of a horse" (Pizlo *et al.*, 2014, p. 58). Though distinct angles are more present in human made synthetic 3D objects like buildings.

Once the building is erected and in use, it is perceived differently by the users and observers as opposed to the construction team. On the one hand this is due to the fact that for many useful functions the precision is not so crucial any more. On the other hand this is due to the fact that we as humans are actually not so good at *quantitative* values and are focused more on *qualitative* values.

It is disputed in Vision research how weak and error prone the human perception of metric – quantitative – perception is[122]. But there is consensus in Vision research that humans have problems with metric distances and angles.

Some researchers like Todd and Norman see it quite drastically:

> The results obtained on all of these tasks revealed large constant errors and large individual differences among observers. There were also systematic failures of constancy over changes in viewing distance, orientation or response task. When considered in conjunction with other similar reports in the literature, these findings provide strong evidence that human observers do not have accurate perceptions of 3D metric structure"(Todd and Norman, 2003)

While other Vision researcher (Lee *et al.*, 2012) (Pizlo, 2008, p. 119) argue that the results get better when additional real world information is available to the observer and the observer is allowed to change the viewing position.

122 For instance the angle adjustment experiment by Pizlo (Pizlo, 2008, p. 23)

In architecture there are some special angles like 45 degree, 60 degree and most prominently the 90 degree angle. The 90 degree angle is used in various rectangular shapes. From a geometry and construction point of view the 90 degree angle can be argued with the Euclidean geometry space and the three axis that makes up the Cartesian coordinate system. But it might be interesting to look how a human observer without a geometry or construction focus perceives this angle.

Form a Vision research point of view the 90 degree angle has some foundation as well. We can distinguish between the 90 degree angle in a vertical (view) and in a planar (plane) setting.

At human scale the gravity is a vertical force. It hits the ground at a perpendicular angle. The human body has an equilibrium sense and we can feel when we stand upright. By correlating our own equilibrium sense with the visual information from our eyes we can judge to some extend if an object that we are looking at is standing upright as well. This also works in a passive setup. We have learned by experience that certain things in our environment are usually upright or flat as well. Researchers like Pizlo even argue that we do not learn this solely by experience but are rather driven by a priori “rectangularity constraint” and this insight can be traced back to researchers like Perkins (1972) and even further to the Gestalt psychologists’ *simplicity principle* (Pizlo, 2008, p. 53).

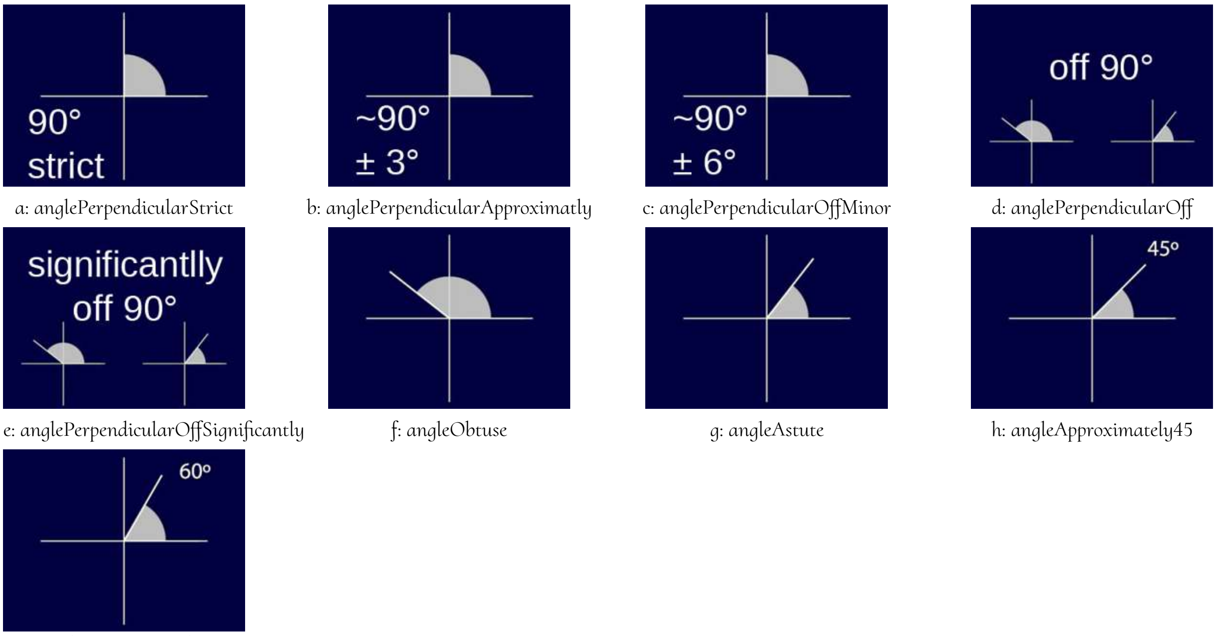
When we look at a photograph of a building and we see a horizon line, a flat surface with roads, light posts or other people walking by, we can infer with some certainty if particular parts of a building stand upright as well. With this helper objects we can also correct some of the camera lens distortions in our mind. Cultural experience teaches us that many walls of buildings are upright because it is economically beneficial to build then this way.

The cognitive argument for a 90 degree angle in a plane are not so strong like in the vertical but still present. Human vision is based on the pair of eyes. If an object is preciously at a *fronto-parallel* orientation towards our eyes we have the ability to recognize this. Though most of the time most real world objects are viewed from a non fronto-parallel orientation. Buildings are especially challenging because of their scale relative to the human observer. When we perceive a building on site it is not so easy. At a street corner we might look at an edge. It is hard to judge if that angle is exactly 90 degree, or a bit off.[123] When we look at buildings from photograph we have a different problem: The lens distortion of the camera is part of the 2D photograph and we must

123 When we look at a map of a typical central European city we most likely see many streets that are not merging perfectly in a 90 degree. Still at pedestrian level this is much harder to recognize. We do assume that many buildings are perpendicular even in the plane view because they seem to be easier to construct. Though this can not always be argued with economical reasons. It might very well be cheaper to align to a slightly off fire wall of a neighbour building, or move an angle a bit to enclose a little bit more space which can be sold with more financial profit.

correct it in our mind. This is especially challenging for planar 90 degree angles where a horizon line or other context objects are of little help.

When we move to a task to compare angles in different buildings the imprecision in judgement might even increase. Is a Building Shape with an 88 degree angle so much different to one with a 92 degree angle? Compared to other buildings that might be totally off 90 degrees, like f.i. 67 degrees the previous difference becomes relative. Sometimes we can see – or at least assume – that there is a strict 90 degree angle because it is an obvious design decision of the architects.



a: anglePerpendicularStrict b: anglePerpendicularApproximatly c: anglePerpendicularOffMinor d: anglePerpendicularOff e: anglePerpendicularOffSignificantly f: angleObtuse g: angleAstute h: angleApproximately45 i: angleApproximately60

Figure 163: Classification set: Angle (Plane- and View-Orientation) (all items)

The first five angle classification items start with the strict 90 degree angle and then add more and more variance. This variance does not hint if the angle is changing towards acute or obtuse angles.[124]

- anglePerpendicularStrict (Figure 163a) – this is the default item
- anglePerpendicularApproximatly (Figure 163b)
- anglePerpendicularOffMinor (Figure 163c)
- anglePerpendicularOff (Figure 163d)
- anglePerpendicularOffSignificantly (Figure 163e)

The next two angle classification items are about acute and obtuse. The terms follow Critchlow (1969, p. 106).

124 The diagram pictures are actually referring metric values like ~90° plus/minus 3° or 6°. These should not be taken so preciously but it's simply hard to come up with a sketch for a anglePerpendicularOffMinor

- angleObtuse – In the view-orientation obtuse angle can hint that there is a dome or vault shape. In the plane-orientation obtuse angles can hint that there is a cylinder or a dome shape as well. (Figure 163f)
- angleAstute – This items is seldom used in the plane-orientation but can be useful in the view-orientation to hint the presence of spikes and high points. (Figure 163g)

The last two items are specialisations of the astute angle: the 45 degree and 60 degree angles. They are significant angles in 3D Geometry (Critchlow, 1969, p. 106).[125] They are more routed in Geometry then in Vision research and they suffer from the same problems like the 90 degree angle as well. They were mainly introduced because some World Exposition pavilion have some strict geometric shapes that can even be recognized from photographs by an observer.

- angleApproximately45 (Figure 163h)
- angleApproximately60 (Figure 163i)

The 45 degree and 60 degree angle items[126] might be candidates for removal in a future version. Vision researchers like Biederman already omitted such detailed items arguing with human performance:

> "As noted earlier, one reason not to posit a representation system based on fine quantitative detail, for example, many variations in degree of curvature, is that such absolute judgments are notoriously slow and error prone unless limited to the 7 + 2 values argued by Miller (1956)." (Biederman, 1987, p. 126)

7.3.2. Edge (Plane- and View-Orientation)

Even though not completly understood and still discussed, many Vision researcher generally agree that "There is an abundance of evidence from pictorial art and human psychophysics that occlusion contours and edges of high curvature play an important role in the perception of 3D shape" (Todd, 2004, p. 118) . We will see this reappears when we will discuss the "Feature" classification set. It should also be valuable to look at edges at are more "zoomed in" level. This *Edge* classification set could have been named more descriptive the "edge cross section" classification set, but then it would be a bit clumsier to reference.

The Edge classification set is best visualised with a orthogonal section view of an edge.[127] But it should be pointed out that it is not a classification set that is concerned with

125 The 30, 45, 60, 72, 90, 180, 360 degree angles are special in 3D Geometry and are emphasised in publications like "Order In Space" by Critchlow (1969, p. 106)

126 angleApproximately72 was also considered, but dropped early, due to lack of buildings that would have utilised it.

127 Sketches that visualise the *linear* edge similar to IL 22 could be added in a future version.

corners but rather the linear edges which are visually more prominent in most 3D shapes.[128] The proposed classification set differs from IL 22 (Otto, 1988, pp. 38, 39). It contains only four items that are common in buildings.

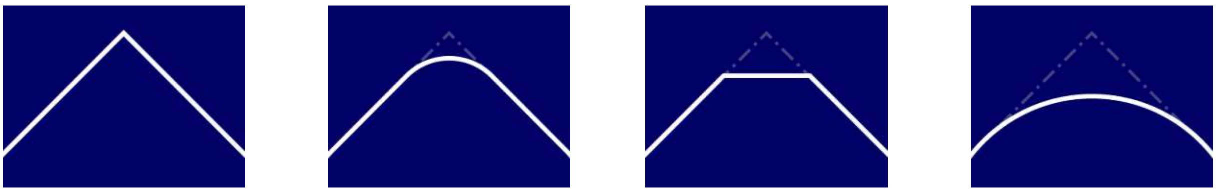
Depending on the scale of the building and the zoom level of the observer, one can distinguish more and more edges. For instance a dome could be constructed as a geodesic sphere and therefore have a lot of planar surfaces with edges. Really curved or filleted construction elements are less common then some with sharper edges. But for Building Shape classification we usually look at the Building Shape from a less detailed zoom level and need to classify the *impression* of the Building Shape and not the smallest *construction detail*. Though hybrid classification of shapes is possible and sometimes makes sense. For instance for low faceted geodesic domes (see Figure 164) where we can assume that the architect likes both properties.

Figure 164: X1 - Expo 2010 Innovative Tours heme Pavilion (Shanghai)

Figure 165: V2 - Expo 1970 Italy Pavilion (Osaka)

Figure 166: T1 - Expo 2012 Samsung Corporate Pavilion (Yeosu)

In human made shapes at the scale of buildings the edges can be seen as a constructive necessity or as an explicit design element. When architects pick a polygonal shape from the stricter realm of geometry then edges are often sharp as well, to emphasise the design. (See Figure 165) The opposite is possible as well and use of fillet edges can have a strong visual effect. (See Figure 166)



a: edgeSharp b: edgeFillet c: edgeChamfer d: edgeSmooth

Figure 167: Classification set: Edge (Plane- and View-Orientation) (all items)

- edgeSharp (Figure 167a) – this is the default item
- edgeFillet (Figure 167b)

128 There is also no *Corner* classification set in the proposed system. Corner classification is present in IL 22 (Otto, 1988, p. 40). Of course corners exists but their quantity and significance is hard to reason about. Corners that constitute themselves as high points and low points can be described with the *Feature* classification set.

- edgeChamfer (Figure 167c) – This classification item exist mostly for completeness sake. In the set of 80 World Exposition pavilions there were surprising few building shapes that used this as a significant design statement.

The last item of the edge classification set has a special role:

- edgeSmooth (Figure 167d) – Its a kind of negation, and points out that edges are not present – or at least not significant – but rather their absence. This makes it possible to describe shapes like cylinders, spheres and amorphous blob-shapes.

7.3.3. Tilt

The classification set described in this section about tapering and widening is similar to the *Angle* and *Edge* classification sets. It describes abstract concepts that could be applied to plane-orientation as well as to view-orientation. It seems to make sense from a geometry point of view. But the benefits to apply it to plane-orientation are not obvious. It is challenging to argue this from a cognitive point of view. There are good arguments from cognitive science for a view-orientation and this is now the focus of the whole *Tilt* classification set.[129]

We will use the term *tilt* to describe the slope that a distinct building part can have.[130] We consider inclination that makes a shape narrower at the top as well as the opposite effect that makes a shape broader at the top then at its bottom. Because we concentrate on *tilt* in regards of the *view-orientation* the normal/neutral position of tilt is perpendicular to the ground plane which is defined by gravity. When the shape is becoming narrower towards its top we call this *taper*. When the shape is becoming broader towards its top we call this *widen*.

Gravity plays a central role in human vision for the perception of tilt. Everything that was mentioned about gravity in the *Angle* classification set also applies here.[131]

---

129 Tilt with plane-orientation is actually implemented in the software but was not filled out in any of the World Exposition pavilion data files. It falls back to a default value which is the same everywhere.

130 It is not easy to pick the correct English word for this classification set. Especially as English is not the native language of the author. An alternative term is *slant*. It relation to tilt: "Tilt is the direction of slant. Tilt specifies the axis around which the plane is rotated in depth and away from the frontal plane, and slant specifies how much the plane is rotated." (Pizlo *et al.*, 2014, p. 35). As *slant* is quantitative term, we prefer *tilt*.

131 A visual demonstration that an a prio *gravity* constraint and a *horizontally of surfaces* constraint are valid approaches is given by Pizlo (2014, pp. 217, 175). The constraints help to solve the Figure-Ground-Organisation (FGO) problem. They assist to retrieve meaningful shape information from a single 2D image. A famous painting by Jacopo Bassano "Last Supper" from the year 1542 is presented upside down followed by the normal version. The reader is asked to identify the number of people. The *gravity* constraint and the *horizontally of surfaces* constraint are influences for the presented *Tilt* classification set.

Vision researchers like Pizlo (2014, pp. 179, 183, 184, 217)argue that humans are trying to recognize the *ground plane* while looking, interacting and planing spatial actions.[132] Pizlo claims that humans have at least two ways to find the ground plane:

- The first way is with the help of information sensed by the vestibular system in the inner ear. This equilibrium sense works when the object that we are looking at are in our real environment and we can combine the equilibrium input with the visual input.
- The second way is independent from the equilibrium sense and only requires visual information.[133] Pizlo assumes that humans have special capabilities to recognize symmetry in objects they perceive. Many of these symmetries are mirror-symmetrical perpendicular to the ground plane. Humans look for these context objects to pin point the ground plane. This works by looking for at least three points where the object touches the ground (Pizlo *et al.*, 2014, p. 189). We usually live in a space where most of the time we have plenty of context objects at our disposal. With each additional context object our mental calculation about the position of the ground plane becomes more accurate.

The second way does not only work in real environments but enables us to recover the ground plane from a photograph as well (Li *et al.*, 2012).[134]

Additionally we learn to cope with human made things in our environment. We remember their shape and their typical position in regard to the ground plane. We know from experience that street signs and street lamps are usually perpendicular to the ground floor. We also assume that a *typical wall* in a typical western building is perpendicular to the ground plane. Walls are build this ways for various reasons but two of them are: simplified construction and economical benefit. It can be simpler to plan and construct a perpendicular wall because the gravitational load is flowing right through the middle of the element. Also the weight of the wall can be integrated into structural calculation in a simple manner. The economical benefit is driven by the fact that buildings are often sold by the square meter of space that a human can use well.

132 At the scale relevant to building shapes, the ground plane is assumed to be flat and perpendicular to the gravity of the earth. Of course a building can be build on a slope, but even then humans would build floors that are flat without any slope. World Exposition pavilions – similar to most buildings – are build on flat areas.

133 Britannica Encyclopedia supports the importance of the two ways: “Despite all this sensory input, most individuals receive the bulk of the information about their environment through the sense of sight, while balance or equilibrium (vestibular sense) apparently ranks next in importance.“
Järvinen, E. Jaakko , Fieandt, Kai V.J. von , West, Louis Jolyon and Korkala, Pekka Yrjö. "space perception". Encyclopedia Britannica, Invalid Date, https://www.britannica.com/science/space-perception. Accessed 30 October 2021.

134 Li et al. is published by Pizlo’s team as well. Even when we are a bit more cautious about Pizlo’s approach other Vision researchers have found out that our ability to recover shapes from photographs improves significantly when more then one photograph of an object is available and where the point of view is different by for instance 45 degrees. This is discussed at the end of chapter 7.2 and in chapter 11.1.

Because humans are moving around upright through their environment it is often more profitable to have perpendicular walls. Humans are also more comfortable standing on a flat horizontal floor then on a slope.

Figure 168: H3 - Expo 2010 Australia Pavilion (Shanghai)

Applied tiltApproximatelyNone

Figure 169: B1 - Expo 1970 Soviet Union Pavilion (Osaka)

Applied tiltTaperComplete in one distinct building part

Figure 170: D4 - Expo 2010 Wanke Corporate Pavilion (Shanghai)

Applied tiltWiden and tiltTaper in multiple distinct building parts

For the *Tilt* classification set, it is therefore assumed that humans are good at recognizing neutral upright elements.

Of course many interesting buildings contain elements which are not purely horizontal and vertical. Some of these shapes have a practical reason like gable roofs which are efficient in leading rain water. It can be a design decision from an architect to not follow the expected pattern but rather challenge the users with spatial shapes that are tilted. A free standing pavilion allows for such design freedoms.

The *Tilt* classification set therefore further assumes: When we are efficient to recognize neutral tilt, like vertical walls, we also recognize that something is not vertical. Usually we would skip a tilted object when our task would be to find the ground plane. But when our task is focused around building shape this suddenly helps. When we want to remember a building shape, or describe how similar two or more buildings are then we have an additional differentiator available.

Figure 171: V1 - Expo 1967 Austria Pavilion (Montreal)

Applied tiltWiden and tiltTaper in each distinct building parts, hard

Figure 172: H5 - Expo 2010 Spain Pavilion (Shanghai)

Applied tiltWiden and tiltTaper in each distinct building parts, soft

Figure 173: Z3 - Expo 1970 Telecomm. Corporate Pavilion (Osaka)

Applied tiltWiden and tiltTaper in "complete" in both directions

When something is not vertical it can either be tapering towards the top or it can widen towards the top. Due to gravity forces and building culture it is common that building shapes taper towards the top. Building shapes that are widening towards the top are less common. We can assume that widening is a stronger differentiator then tapering. Often we have the impression that the more seldom widening is a deliberate design decision by an architects. Tilt is not exclusive in one of the directions within a distinct building part. Figures 171 and 172 show pavilions with taper and widen within one distinct building part. Figure 173 shows an example with contains the two extremes tiltTaperComplete and tiltWidenComplete in a single distinct building part.

In the proposed classification system it is possible (Figure 174) but not necessary that a tapering is complete or constant or ending in a single high point. The top of the tapering does not need to be constant from all sides. Ridges (Figure 175) or asymmetrical tops are also present. A dome like structure is assumed to be tapering as well (Figure 176).

Figure 174: D7 - Expo 1970 Bulgaria Pavilion (Osaka)

Applied tiltTaperComplete

Figure 175: F7 - Expo 1970 Gas Corporate Pavilion (Osaka)

Applied tiltTaperComplete on ridge

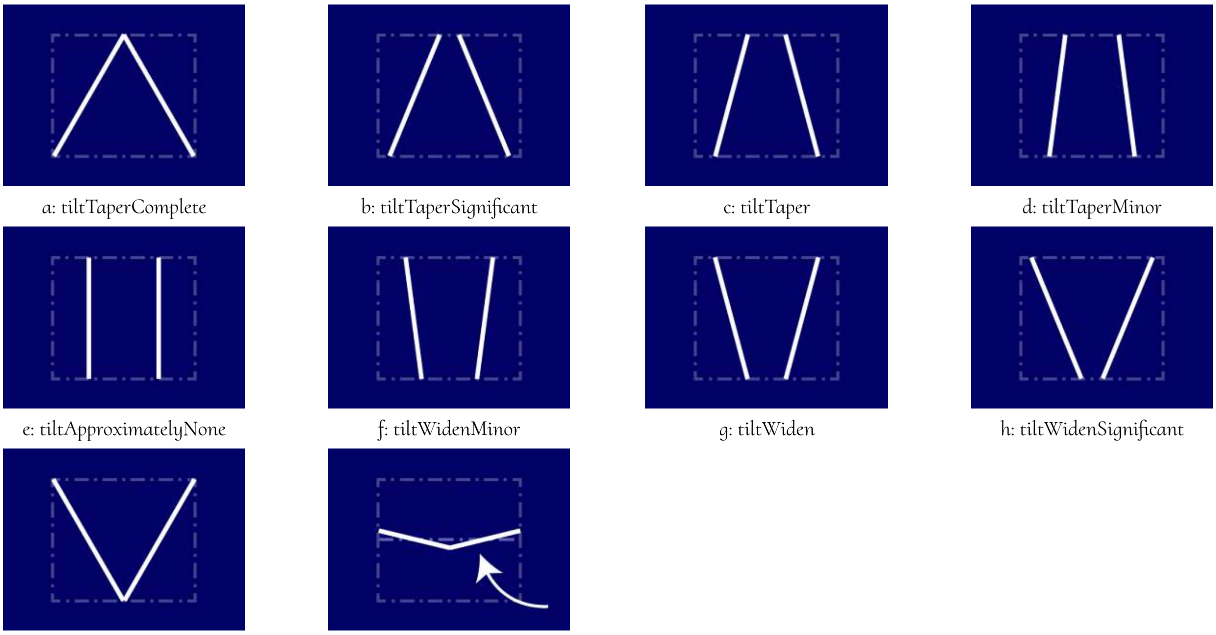
Figure 176: X3 - Expo 1970 France Pavilion (Osaka)

Applied tiltTaper on dome

It is easy to see in Figure 177 that there is a certain flow of the items and that the tilt effect starts completely tapered, then transforms towards the neutral vertical and then again increases as the widening effect. There is a gradient of quantity. We will discuss in the Curvature classification set that humans are not very efficient at quantity, so the question arises why Tilt has these quantities. The argument is similar to the Angle classification set. It is driven by building culture and tradition rather then cognitive science.

- The *approximatelyNone* quantity identifier is the neutral position. As observers we can not be completely certain that we are correct until we would measure it on site. Therefore we hatch the statement and tolerate small deviations.
- The *minor* quantity identifier is supported by the fact that architects wants to challenge their user with interesting shapes but are still bound by the requirement to provide enough usable indoor space. A whole class of building shapes are tapered or widened *just a bit*. Because classification is about identifying classes it makes sense to include this insight.
- The *normal* quantity identifier is omitted in the technical word. Tilt is present.
- The *significant* quantity identifier is important because there are buildings that taper a lot or even nearly completely but have a different top, which is not a spike

- The *complete* identifier points out that the end of the taper or widen tilt is reduced to a single point *from a certain viewpoint*. We tolerate ridges like in gable roofs.



a: tiltTaperComplete b: tiltTaperSignificant c: tiltTaper d: tiltTaperMinor
e: tiltApproximatelyNone f: tiltWidenMinor g: tiltWiden h: tiltWidenSignificant
i: tiltWidenComplete j: tiltViewFromBelow

Figure 177: Classification set: Tilt (View-Orientation) (all items)

The items in the Tilt classification sets are a continuous sequence:[135]

- tiltTaperComplete (Figure 177a)
- tiltTaperSignificant (Figure 177b)
- tiltTaper (Figure 177c)
- tiltTaperMinor (Figure 177d)
- tiltApproximatelyNone (Figure 177e) – this is the default item
- tiltWidenMinor (Figure 177f)
- tiltWiden (Figure 177g)
- tiltWidenSignificant (Figure 177h)
- tiltWidenComplete (Figure 177i)
- tiltViewFromBelow (Figure 177j)

The last item tiltViewFromBelow is special. When we look at the sequence of sketches it makes sense that we can continue to increase the slant angle. This leads towards a cantilever distinct building part. It might be arranged on top of a smaller base. This is the design of the Kaleidoscope. With Figures 178, 179 and 180 we want to enable a small

135 The neighbourhood relationships are also modelled as *Weak References* and can be seen in Appendix B (19.2).

thought experiment: we can imagine that we are present at the World Exposition sites of these buildings as a pedestrian. Approaching buildings and viewing part of their volume from a below point of view constitutes a commonality. Imagine the contrast of approaching a more conventional building with tiltApproximatelyNone that touches the ground everywhere. Chapter 10 will compare in detail and with a lot of photographs how cantilevered building shapes relate to each other.

Figure 178: E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)

Applied tiltViewFromBelow

Figure 179: F7 - E2 - Expo 2010 China Host Pavilion (Shanghai)

Applied tiltWidenSignificant

Figure 180: E1 - Expo 1967 Canada Host-Pavilion (Montreal)

Applied tiltWidenComplete

In theory there could be the opposite of tiltViewFromBelow which would be: tiltViewFromAbove, but it is not included in the Tilt classification set. The absence of tiltViewFromAbove can be discussed from two different perspectives:

- As a thought experiment we could imagine a building that is actually underground but has a visible flat top surface so we can distinguish it from the surrounding ground. We can have the feeling that we are walking on top of it and "view it from above". But according to our definition of building shape in the introduction chapter 1.2 this kind of building does not have a clear three dimensional shape that we can discuss, as it is mostly underground.[136]
- We can easily imagine that buildings with vertical walls and even all variants of tiltWiden typically are completed with a flat roof, otherwise the geometry would be incomplete. For World Exposition pavilion this assumption can be misleading in a few cases. External pedestrian views might hide hollow parts (see for instance Figure 263). Often the architects of World Exposition pavilions concentrate of the pedestrian level, where the vast majority of users will experience their building. The fact that aerial pictures can be made by people not concerned with construction work is often secondary. The Building Shape classification in this thesis tries to omit these pitfalls by not using any tiltViewFromAbove. This should be acceptable because we try to reference shape properties which give identity to a building shape. With the tiltWiden group one might argue that the widen effect is most likely much more

136 An empty swimming pool has also a perceivable shape, but would typically be called a negative shape. These kind of shapes are not covered by this thesis and empty swimming pools are not buildings, so they would require their own shape classification system. One could imagine or even find real world buildings that might constitute such tiltViewFromAbove but there were not present between the World Exposition pavilion investigated here.

important for the building shape identity then any flat roof on top of it. A complete CGM geometry description would handle this very differently.[137]

A further aspect of tilt that is unfortunately not covered in the software implementation is the connection between *tilt* of a single distinct building part and *tilt* due to the composition of multiple distinct building parts.[138] When a building is composed of more then one distinct building part like the Kaleidoscope the arrangement itself could cause widening or tapering. For instance the fact that the smaller base below the big cylinder of the Kaleidoscope is located below leads logically to a cantilever building and could be inferred from the Syntax Tree part. This fact is actually redundantly covered by the additional tiltViewFromBelow item associated with the cylinder. This redundancy is therefore in the Periphrase. Later in chapter 12.4.2 we will discuss if it is even worth to create Building Shape data for such secondary building parts like the base of the Kaleidoscope. In such optimized cases the information would be lost from the composition information in the Syntax Tree. It would still be preserved from the redundant tiltViewFromBelow in the Periphrase.[139]

7.3.4. Texture

Texture must be perceived spatially, as opposed to a printed or flat pattern. It is usually at a smaller scale then the rest of the shape. If it would be at the same scale one could argue that it is not a texture but rather separate polygonal elements with some composition.

One example of building shape texture would be some balconies that appear at every floor of a high rise building and give it a “stacked boxes rhythm”. Another example could make it possible to augment *Curvature* to solve classification of a geodesic dome. The geodesic dome might be perceived round but at a different scale created out of planar elements. These planar elements might have edges but the angles to their neighbours are very obtuse.

137 Of course one could imagine scenarios beyond World Exposition pavilions where a tiltViewFromAbove could be an important differentiator. In a traditional village with many family home with gable roofs the two only buildings with a flat roof are connected via tiltViewFromAbove. Another example would be a city with hills and valleys (e.g Stuttgart) or many high rises buildings (e.g. Hong Kong) where it is possible for many users to see the roofs and flat roof tops of other buildings. Even on World Exposition sites there are usually some higher lookout points or funicular used by many visitors.

138 See also last paragraph of 6.6.5.

139 Because we decided to not have an corresponding tiltViewFromAbove the information can neither be inferred nor redundantly associated for a building shape that consists of distinct building parts that are stacked on each other.
We can think of the ways how we can describe an Aztec pyramid as an arrangement of a few cuboids that are smaller in relative size towards the top and that create the typical terraces. On the other hand an Egyptian pyramid with full cladding consists of a single distinct building part. Ideally the software implementation could infer the relationship, but unfortunately this is out of scope. For a competing 3D shape similarity algorithm this should be an easier task.

There are two properties:

- Pattern – can be either *striped* or *faceted*. A striped pattern consist of elements that are approximately parallel to each other. A striped pattern has only two neighbour element while a faceted pattern has three or more neighbour elements.
- Regularity – in relation to other elements that also participate in the texture can be either *regular* or *irregular*.

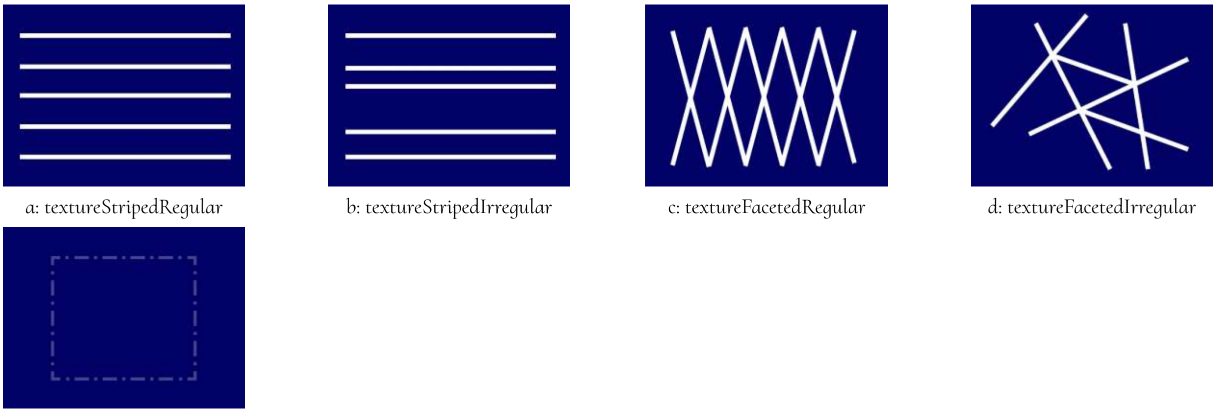


Figure 181: Classification set: Angle (Plane- and View-Orientation) (all items)

The combination of pattern and regularity leads to the following classification items:

- textureStripedRegular (Figure 181a)
- textureStripedIrregular (Figure 181b)
- textureFacetedRegular (Figure 181c)
- textureFacetedIrregular (Figure 181d)

The fifth item is the absence of any prominent pattern which is also the default item:

- textureSmooth (Figure 181e) – this is the default item

We can observe that especially for the striped pattern there is actually no distinction between vertical, horizontal and maybe even diagonal. Currently a vertically striped building would have the same texture item as a horizontally striped building. There are two reasons for this. First, the 80 World Exposition pavilions had only very few striped textured building shapes. Second, it is also a conceptual experiment to state that the pattern is more important then the orientation. When a bigger set of buildings with textures would be classified in a future version, one might consider adding the orientation as well.

7.3.5. Curvature

We mostly follow the concepts from IL 22 (Otto, 1988, p. 26)[140]. We only use a subset and we additionally derive specialized classification items that work well with buildings.

A dictionary definition of *curvature* is:

> a measure or amount of curving; specifically: the rate of change of the angle through which the tangent to a curve turns in moving along the curve and which for a circle is equal to the reciprocal of the radius (Merriam-Webster and Mish, 2011)

Curvature is an *intrinsic* property of a surface and therefore from a shape. So it is not important how the distinct building part is positioned in relation to other distinct building parts as well as towards the ground plane which is determined by the external effect of gravity. When we look at Building Shape we have a *pair of principal curvatures* that are orthogonal at a surface point.[141]

There are various formulas that allow to measure the amount of intrinsic curvature. From geometry we know Gaussian curvature at a given surface point. In Vision research there is also a broader use of *shape index* and *curvedness* (Koenderink and van Doorn, 1992). Shape index can be visualized as a gradient which in favourable for visualisation. Shape index can also be used to show a continuous transformation like in the illustration from Dövencioğlu et al. (2015) :

- convex elliptical – dome (P1 in Figure 182) – synclastic
- convex parabolic – vault (P2 in Figure 182)
- hyperbolic – sattle (P3 in Figure 182) – anticlastic
- concave parabolic – ridge (P4 in Figure 182)
- concave elliptical – cu (P5 in Figure 182)

140 We name our classification set “curvature” as an abbreviation of “curvature of surfaces”. We split up curvature, edge, texture and feature, while IL 22 treats these concepts as parts of surfaces.

141 It is also possible to express curvature as an *extrinsic* property. This can be seen in architecture when approximations of minimal surfaces are anticipated. For instance with textile structures.

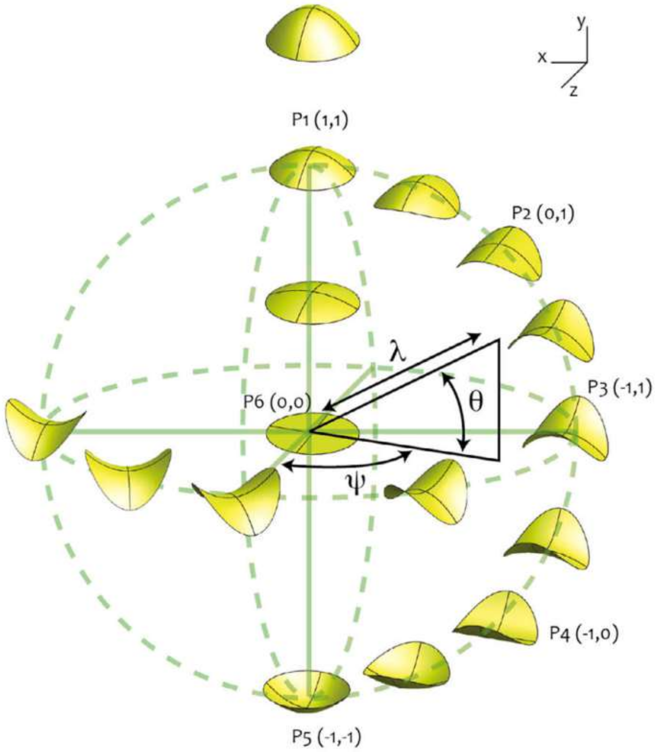


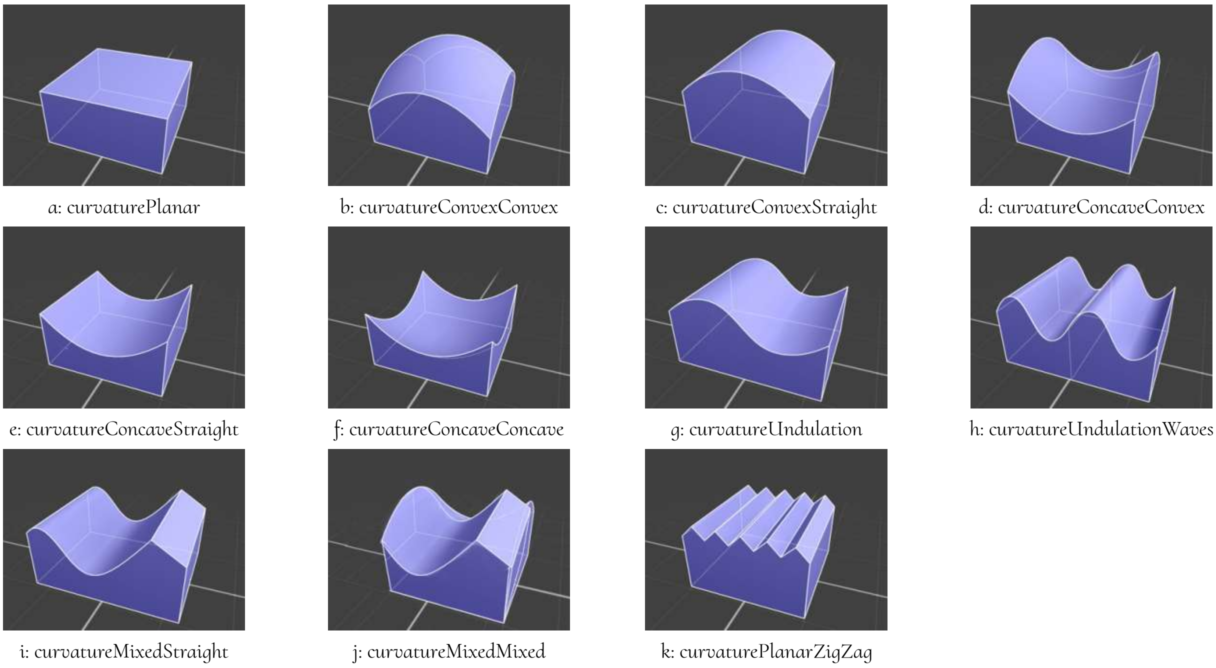
Figure 182: "Fig 3. from (Dövencioğlu *et al.*, 2015) Illustration of the local shape space. Second order curvature is represented by two principal curvature values for each shape, which are essentially derived from two perpendicular lines defining the local surface patch, indicated here by a positive or negative value.

With the mathematical formulas it is also possible to describe the *quantity* of a curvature. So it is possible to express a curvature which is very close to a flat surface and one which is for instance a very expressive hyperbolic. For the construction of a building these quantity information are of course essential. But once the building is erected and people have no access to construction details the situation changes according to Vision researchers like Biederman (1987, p. 126)and Todd which represent the mainstream view[142]:

> observers' judgments about the general pattern of concavities and convexities were quite accurate, but there was one aspect of the apparent 3D structure that was systematically distorted. The judged magnitude of relief was underestimated by all observers, (Todd, 2004, p. 117)

Based on these findings the *Curvature* classification set introduced here does not include any quantity indicators but concentrates on the convexity (positive curvature), concavity (negative curvature) and the absence of curvature (flat surface). Then it extends the set by adding items beyond geometry which are closer to architecture.

142 The importance of *surface vs. shape* and the role of *curvature* is disputed between Vision researcher of the Marr tradition and alternative views like Pizlo. But they all agree that curvature plays a role and should be taken into account. Especially the fact that curvature is a local and intrinsic property makes it attractive to Vision researchers.



a: curvaturePlanar; b: curvatureConvexConvex; c: curvatureConvexStraight; d: curvatureConcaveConvex; e: curvatureConcaveStraight; f: curvatureConcaveConcave; g: curvatureUndulation; h: curvatureUndulationWaves; i: curvatureMixedStraight; j: curvatureMixedMixed; k: curvaturePlanarZigZag

Figure 183: Classification set: Curvature (all items)

The default value is the planar item:

- curvaturePlanar – flat, absence of any curvature. This item is not only special from a geometric point of view, but also some Vision researcher like Perkins (1972) and Pizlo (2008, p. 54; 2014, p. 96) argue that due to the simplicity principles there is also a tendency to see a surface as simple as possible with a *planarity constraints*. Having a surface where the observer does not need to think about curvature because it is absent is always simpler then having one with curvature. This can be argued for many human made objects – including buildings – but there are not that many planar object in living nature. This is the default item. (Figure 183a)

The next group follows the typical geometry and Vision research pattern and describes the shape by pointing out both principal curvatures as a pair:

- curvatureConvexConvex – convex elliptical – dome – synclastic (Figure 183b)
- curvatureConvexStraight – convex parabolic – vault (Figure 183c)
- curvatureConcaveConvex – hyperbolic – sattle – anticlastic (Figure 183d)
- curvatureConcaveStraight – concave parabolic (Figure 183e)
- curvatureConcaveConcave – concave elliptical (Figure 183f)

Shapes with straight curvature in one principal direction are more common in architecture due to simpler construction details. One pattern that can be observed in architecture is the change in surface direction in a wavelike fashion. This is called *undulation* in the Curvature classification set:

- curvatureUndulation – single change in curvature direction (Figure 183g)

- curvatureUndulationWaves – multiple changes (Figure 183h)

A second pattern that we can recognize in architecture is that flat surfaces are used in combination with convex and concave surfaces. This can happen in one or both principal directions:

- curvatureMixedStraight (Figure 183i)
- curvatureMixedMixed (Figure 183j)

The last item is a mixture of curvatureUndulationWaves and flat surfaces:

- curvaturePlanarZigZag – This items is a bit ambiguous because it could be described to some extend with textureStripedIrregular. But the information that there is a wave like up and down is better expressed here. Also it is possible to add *weak references* pointing to curvatureUndulationWaves and therefore associate both items in similarity calculations. (Figure 183k)

H5 - Expo 2010 Spain Pavilion (Shanghai) (Martínez Calzón and Castañón Jiménez, 2013)(Martínez Calzón and Castañón Jiménez, 2010) is an outstanding example of the use of Curvature. In its two Periphrases it uses five items: curvatureConcaveConvex (significant), curvatureUndulationWaves (significant), curvatureUndulation, curvatureConvexConvex, curvatureConvexStraight. Even at the texture level the main cladding is a double curved wicker panel.

Figure 184: H5 - Expo 2010 Spain Pavilion (Shanghai) aerial

Figure 185: H5 - Expo 2010 Spain Pavilion (Shanghai) hall

Figure 186: H5 - Expo 2010 Spain Pavilion (Shanghai) court entrance

7.3.6. Feature

The name "*Feature*" of this classification set is a bit generic but it was challenging to find a better term that can group items like ridges and high points. Still it appears reasonable to group these items.

Conceptually it is close to the IL 22 work (Otto, 1988, pp. 35–40). Thought the research task with the 80 World Exposition pavilions is narrower then the broad goal of the IL 22 publication. Therefore the *Feature* classification set contains a reduced subset. On the one hand we describe linear element and on the other hand we describe points:

- Both follow the same pattern. They are permuted by properties like quantity and local direction.
- Both are a very reduced subsets of broader things: a general *Edge* classification set[143] and a *Corner* classification set.

CAD and CGM based systems have the goal to safe 3D data in a way so it that can perfectly reconstruct the geometry each time a file is opened in a visualisation software. Precise description of vertices and edges with mathematical models like Bezier and NURBS curves are common in such use cases.

In shape perception *edges* have a different role. They help with figure-ground organisation so the human mind can concentrate on smaller areas to do useful tasks. This is usually called the outline of an object. It is not required that an outline is also an internal edge. Within the same object they represent areas of high curvature or even sharp abrupt changes and help humans to recognize different parts of a shape. Vision researcher proved that human participants are quite good at tasks involving ridges and valleys (Todd, 2004, p. 119). When two or more edges meet each other at a single point we commonly referr to this point as a *corner*.

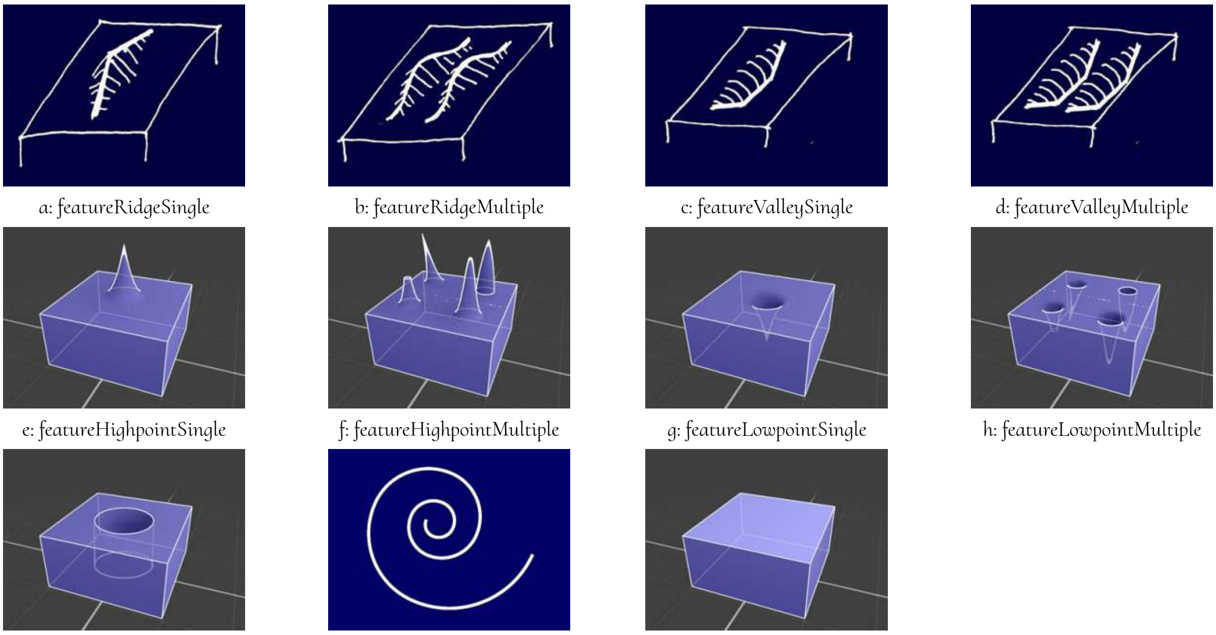
Edges and corners are omnipresent especially in human made objects like buildings. Therefore it would require a lot of work to describe all of them. Building Shape classification tries to focus on the part of a Building Shape that are important for the its *identity*. We will concentrate only on special edges and special corners:

- A *ridge* is an edge that draws special attention. We could approach this from a geometry point of view and require that a ridge has an angle sharper then 90 degrees. This geometric rule helps as a general guide line but neither Vision research or IL 22 are so strict in their definition and would allow obtuse ridges as well, when they crease mostly smooth objects. So the soft term *draws special attention* is important here.
- A *valley* is the inverse of a ridge.
- A *high point* is a kind of corner that draws special attention. In some cases like cone-like shapes it is strictly speaking not a corner were edges meet but a special geometry point. We can think of high points as pointed projections. High points are local properties. A star like building could have high points pointing in many direction and not only vertically up. But building tradition and construction concerns usually lead to vertical high points.
- A *low point* is the inverse of a high point. It is a seldom feature in Building Shapes and is sometimes referred to as a naval.

143 Please notice that the edge classification set, already introduced earlier, is mostly focused on the "edge cross section", which has a visual impact, but does not describe how the edge behaves along its axis.

Especially the IL 22 book shows a wealth of different ridges, valleys, high points and low points. Is also points out that the tip does not necessary need to converge to a single point but could have a special three dimensional characteristic as well. For instance be rounded, truncated, or branching, etc. The wealth of possibilities documented in IL 22 is inspiring but for the task to classify the 80 World Exposition pavilions this was to fine grained and might be introduced in the future when more buildings would use these features. Building collections of radio towers, skyscrapers or ecclesiastical towers would potentially be drivers for this fine grained usage.

The cardinality is the only additional property. We distinguish between *single* and *multiple*. A pattern based on Fibonacci numbers like with the *Cardinality* classification set appeared unnecessary here. Again this might be due to the relative low number of World Expositions pavilions that have features and might change in the future.



a: featureRidgeSingle
b: featureRidgeMultiple
c: featureValleySingle
d: featureValleyMultiple
e: featureHighpointSingle
f: featureHighpointMultiple
g: featureLowpointSingle
h: featureLowpointMultiple
i: featureLowpointCourt
j: featureSpiral
k: featureNoSignificant

Figure 187: Classification set: Feature (all items)

The default item is the negation:

- featureNoSignificant – the absence of any special feature (Figure 187k)

The next block is the permutation with the single or multiple property:

- featureRidgeSingle (Figure 187a)
- featureRidgeMultiple (Figure 187b)
- featureValleySingle (Figure 187c)
- featureValleyMultiple (Figure 187d)
- featureHighpointSingle (Figure 187e)

- featureHighpointMultiple (Figure 187f)
- featureLowpointSingle (Figure 187g)
- featureLowpointMultiple (Figure 187h)

The next item is a special case of a low point:

- featureLowpointCourt – it is a low point that is so deep that it penetrates the whole shape and reaches the other end. An alternative term could be *hole*, but the term *court* simply represent the building tradition that these holes are nearly always vertical and they reach the ground plane. They can be used as courts where they serve architecture function like access to light, creation of privacy, etc.. (Figure 187i)

The last item is a special case.

- featureSpiral – Originally the spiral was a special element in the *Tilt* classification set. But once the decision was made to neglect *tilt with plane-orientation* it seemed appropriate to move spiral into the feature classification set. A spiral can be seen as a special kind of ridge and usually draws the attention of a viewer when encountered at the scale of a building. Though it should be pointed out that a spiral is actually not such a seldom shape in World Exposition pavilions. Similar to the New York Guggenheim museum it is an efficient shape to guide huge quantities of visitors through an exhibition and additionally be able to work with the vertical axis. (Figure 187j)

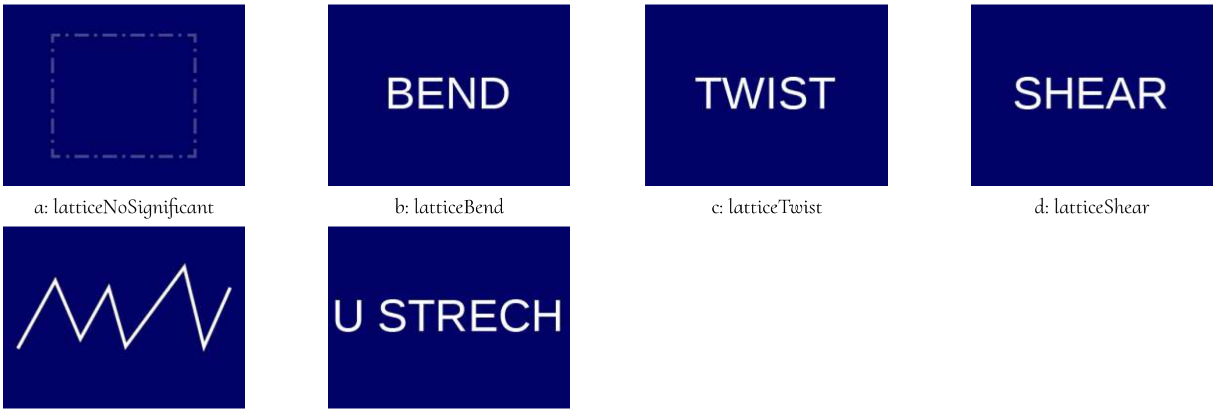
7.3.7. Lattice

The term *lattice* which gives this classification its name, is borrowed from 3D creation software like Autodesk Maya[144] and Bender. In these software packages a lattice box with few control vertices is created around a potentially complex main object. It is possible to manipulate bigger areas of the main objects by moving around few lattice points. This allows for the shape of the main object to preserve most of its original shape qualities while getting additional shape qualities like *bend* or *twist*.[145]

The already introduced Tilt classification set is actually related to lattice transformations like *taper* or *flare*. But due to the interaction with gravity and wider use it got its own set.

144 In Autodesk 3D Studio this is called a Free-Form-Deformation-Box (FFD-Box)

145 In Autodesk Maya as well the other 3D creation software packages there is actually a related set of modifiers called *nonlinear deformers*. They contain deformers like: bend, flare, sine, squash, twist and wave. Essentially they give one more control over a lattice transformation by showing only values that are relevant for the named task. E.g. the twist deformer will show information only relevant to twisting and not show any lattice. In the end these streamlined deformers apply their additional shape transformation the same way like a lattice. But lattice also allows free from deformation like arbitrary noise and unproportional stretch and was therefore chosen as the grouping term.



a: latticeNoSignificant b: latticeBend c: latticeTwist d: latticeShear

e: latticeNoise f: latticeStrechUnproportional

Figure 188: Classification set: Lattice (all items)

The default items is the negation:

- latticeNoSignificant – the absence of any significant lattice transformation. (Figure 188a)

The next group of items affect the main object in a predictable way:

- latticeBend (Figure 188b)
- latticeTwist (Figure 188c)
- latticeShear (Figure 188d)

The last group of items contains some randomness and arbitrary modifications:

- latticeNoise (Figure 188e)
- latticeStrechUnproportional[146] (Figure 188f)

The Lattice classification set is by no means complete, as we can see by the rich choices available in 3D creation software. Above items occurred in the 80 World Exposition pavilions and seem to be present in architecture.

There are related ideas in Vision research. Biederman uses in his *Geons* a system of generalized cones (see chapter 5.3.2) The cone surface takes care of the taper and unproportional stretch transformation while the axis can produce bend, twist and shear transformation. The choice to follow the lattice analogy rather then Biederman's generalized cones analogy is rooted in the fact the we want to transform whole Building Shapes. These whole Building Shapes might already be more complex then what we can achieve with generalized cones.

A further deviation to Vision research like the work from Pizlo is that his team concentrates on global and local symmetry. For instance when a non-rigid flower stem bends in the wind the local symmetry of various sections of the stem is preserve. For

146 There is an unfortunate typo in "Strech" vs. "Stretch" which made it into the technical implementation.

Pizlo it would be important to look at the flower over time and still recognize that it is the same flower, because his focus and definition of shape gravitates around self similarity. For building shape classification we are interested in the more general similarity between different shapes. Therefore a significant twist in two Building Shapes where the original objects are quite different is still something that connects these two buildings.

7.3.8. Proportions

This classification set is named *Proportions*. It is a term that is widely used in architecture and arts. Some other disciplines also use the related term aspect ratio. Indeed the ratios of width, depth and height are at the centre here.

In buildings we can distinguish between *local* and *global* proportions. *Local* proportions are concerned how construction elements like windows are positioned and scaled towards each other and neighbouring and enclosing construction elements. *Global* proportions are concerned with the width, depth, height ratio of the whole building. A high rise building has usually different global proportions then a train station or a single family house even when the all use the same local proportions for the windows. This classification set works with *global* proportions.

Global proportions can be described by a bounding box that includes most of the geometry of a building. By using a box we can express proportions with a triple of attributes: width, depth and height. One disadvantage to force Building Shapes into bounding boxes is that the box might be in contradiction to the geometry of the building shape. For example a pentagonal building or a round dome. This disadvantage must be accepted as the advantage of the just three attributes makes it possible to compare proportions of two Building Shapes. In visualisation software a bounding box is often visualised as a thin line that suggest sharp edges. While this is useful in 3D creation tools it should be avoided in building shape classification because it suggest that the described building shape has sharp edges as well. As a compromise the proportions items are visualised as box with significant filleted edges.

The proportions classification set is *extrinsic* as it is influenced by gravity and the position towards the ground plane. Otherwise it would not be possible to distinguish between a high rise building and a train station.

The golden ratio is used as a multiplier for the attributes. By using a constant golden ratio it is possible to create a two dimensional table which is easy to understand like in Figure Figure 189. We start from the centre where the three attributes are the same. This represents a cube with fillet edges and is named proportionZeroZeroZero. By *multiplying* the third attribute – height – one time with the golden ratio[147] of 1,618… we arrive at

147 The golden ratio is also the ratio that Fibonacci sequence pairs are converging towards. We will see the use of Fibonacci numbers in the *Cardinality* classification set. The argument there is similar to the one here.

proportionZeroZeroP1 which is located right above proportionZeroZeroZero in the table. When we multiply another time by the golden ratio we arrive a proportionZeroZeroP2, which is again located right above. We can see a tower like proportion. We can do this also in the other direction where we *divide* the height attribute one time by the golden ratio proportionZeroZeroM1 which is located right below the cube in the middle. When we divide it again; we arrive at proportionZeroZeroM2 which is located again below.[148]

One important decision made in the use of this *proportions* classification set, is that there is no strict distinction between front side, left side, right side and back side. This is argued with the type of buildings that has been investigated. Pavilions are usually free standing buildings which differs from denser urban environments where we might argue that the street facing facade is the front side. There are also pedestrian streets on World Exposition sites, but often the bigger pavilions are located at intersections and can be viewed from more then one side.[149] Often such a corner is emphasised by the architects. A generalisation like “the front is always where the entrance is” does not work well for all World Exposition pavilions. Due to the amount of people that enter the building and the queueing areas it is not an uncommon solution to have the entrance at the back or at a small spot on the side. The exit is usually detached from the entrance and might be more prominent then the entrance.

With the decision to not discriminate between front and side the classification set must be able to reflect this as well. When we inspect the grid in Figure 190 we can see that for instance proportionP1ZeroP1 (to the upper right of the centre) and proportion-M1ZeroZero (to the left of the centre) are actually the same shape from a different point of view. This was solved technically with the use of the *Weak References* (see chapter 9.3) which allow to have weighted associations between items. There is a named relationship hasVeryStrongLink between these two items. Additionally proportionP1ZeroP1 has not only links to its own direct neighbour items but also to all the neighbours of proportion-M1ZeroZero as well.

The use of the golden ratio creates visually obviously different items without being to big as a step. With a factor of 2, the user might look for an item in between.

148 The letters “P” and “M” in the odd technical names like proportionZeroZeroP1 and proportionZeroZeroP2 are the stepping distance from the central cube that represent an origin point. “P” stands for *plus* and “M” stands for *minus*. One could argue that the letters should be “M” for multiply and “D” for divide. At the end the technical names are there for technical reasons so software systems can better handle the data. A look at the sketch is much more helpful, then an effort to understand for instance: proportionP1ZeroM2

149 The World Exposition in Milan 2015 was a bit different. Due to the master plan there was a dominant axis at which the majority of pavilions have been located. This lead to very narrow and long building sites and an obvious front side for these pavilions.

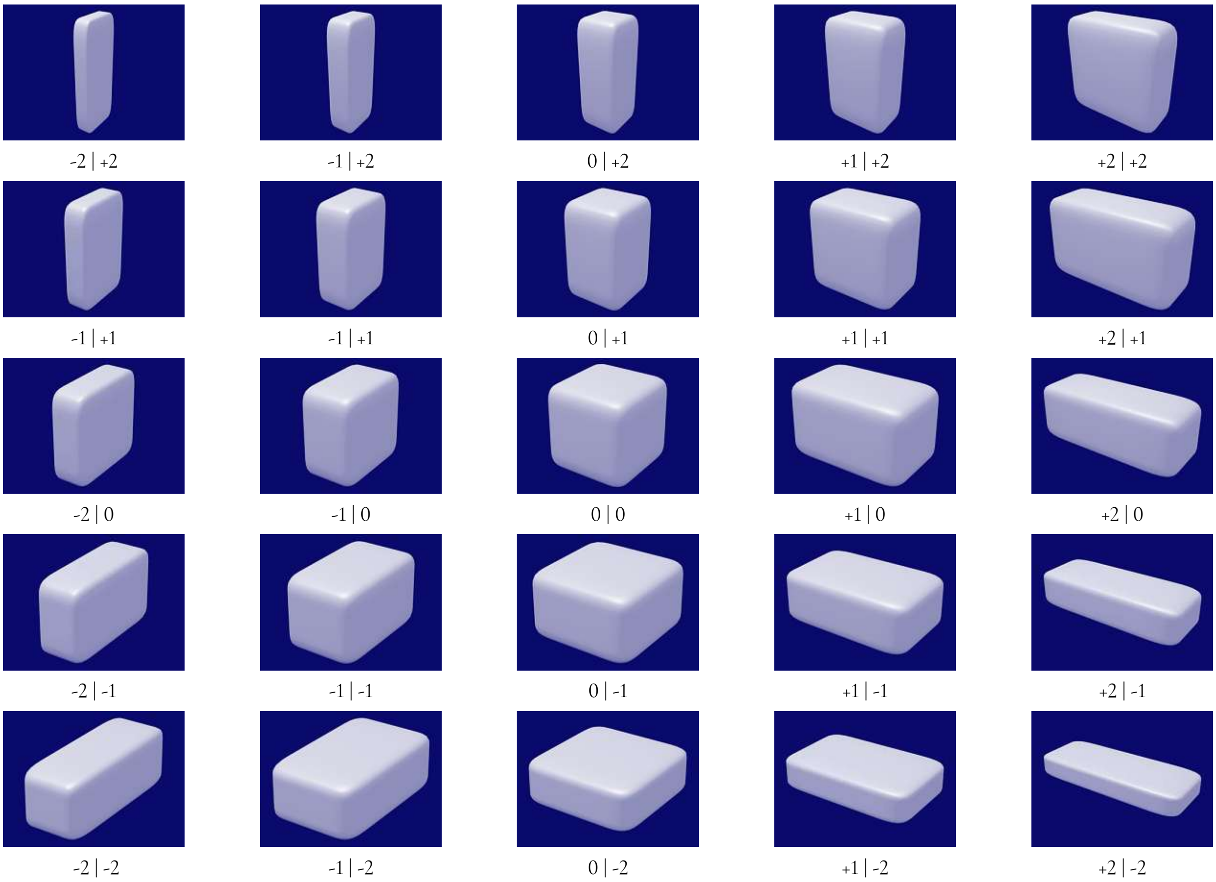
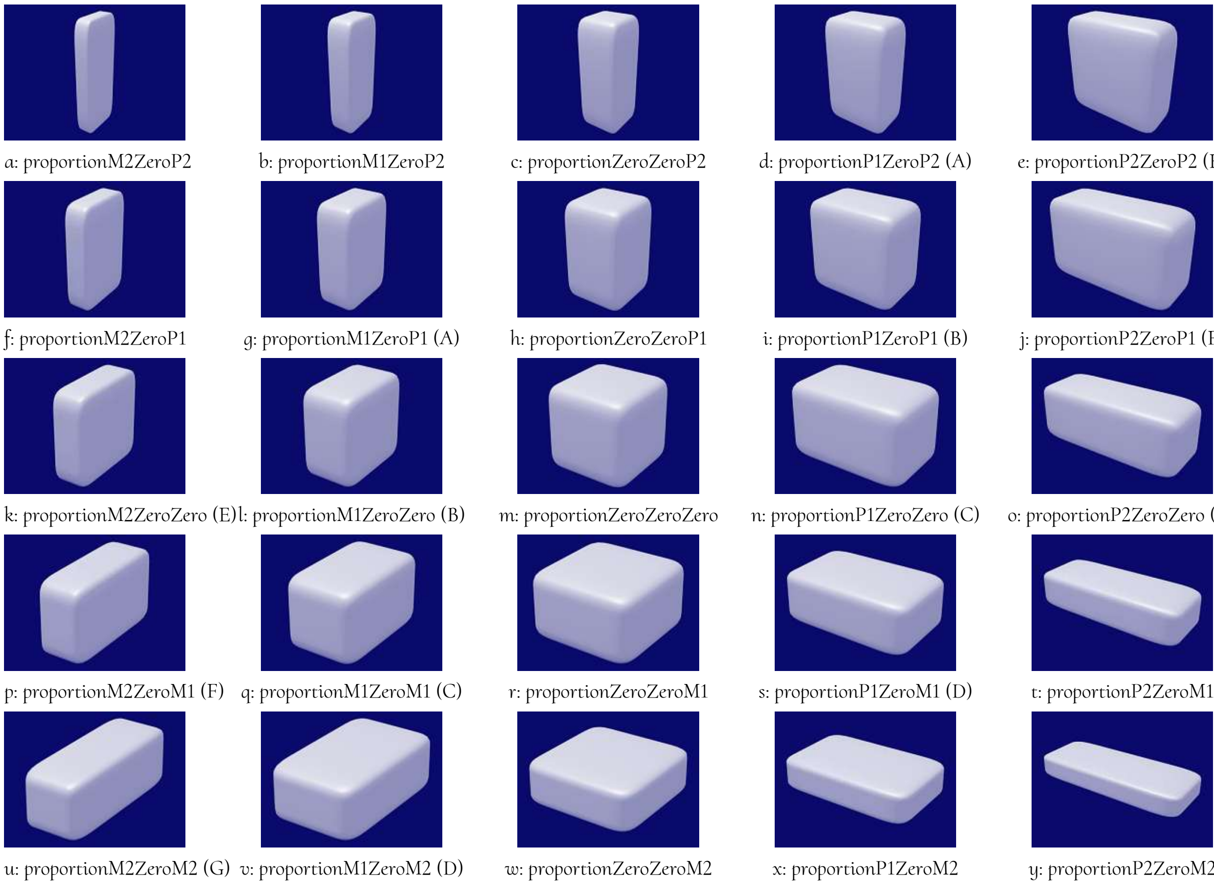


Figure 189: Classification set: Proportions – systematic view

The full listing of all references is documented in Appendix B (19.2). The pairs of sibling items are marked up with the capital letters A to G in Figure 190. This theoretically reduces the set from the 25 visible in the table to 18.

An enumeration of all items with text bullets is not so intuitive like the tables of Figure 189 and Figure 190 but for completeness sake we will list them here by simply starting at the top left and going through row by row, like in a text, until we reach the bottom right. The capital letters points to their sibling.



a: proportionM2ZeroP2 b: proportionM1ZeroP2 c: proportionZeroZeroP2 d: proportionP1ZeroP2 (A) e: proportionP2ZeroP2 (E)
f: proportionM2ZeroP1 g: proportionM1ZeroP1 (A) h: proportionZeroZeroP1 i: proportionP1ZeroP1 (B) j: proportionP2ZeroP1 (F)
k: proportionM2ZeroZero (E) l: proportionM1ZeroZero (B) m: proportionZeroZeroZero n: proportionP1ZeroZero (C) o: proportionP2ZeroZero (G)
p: proportionM2ZeroM1 (F) q: proportionM1ZeroM1 (C) r: proportionZeroZeroM1 s: proportionP1ZeroM1 (D) t: proportionP2ZeroM1
u: proportionM2ZeroM2 (G) v: proportionM1ZeroM2 (D) w: proportionZeroZeroM2 x: proportionP1ZeroM2 y: proportionP2ZeroM2

Figure 190: Classification set: Proportions (all items)

row one – P2:

- proportionM2ZeroP2 -2 | +2 (Figure 190a)
- proportionM1ZeroP2 -1 | +2 (Figure 190b)
- proportionZeroZeroP2 0 | +2 (Figure 190c)
- proportionP1ZeroP2 (A) +1 | +2 (Figure 190d)
- proportionP2ZeroP2 (E) +2 | +2 (Figure 190e)

row two – P1:

- proportionM2ZeroP1 -2 | +1 (Figure 190f)
- proportionM1ZeroP1 (A) -1 | +1 (Figure 190g)
- proportionZeroZeroP1 0 | +1 (Figure 190h)
- proportionP1ZeroP1 (B) +1 | +1 (Figure 190i)
- proportionP2ZeroP1 (F) +2 | +1 (Figure 190j)

row three – Zero:

- proportionM2ZeroZero (E) -2 | 0 (Figure 190k)

- proportionM1ZeroZero (B) -1 | 0 (Figure 190l)
- proportionZeroZeroZero 0 | 0 (Figure 190m) neutral centre
- proportionP1ZeroZero (C) +1 | 0 (Figure 190n)
- proportionP2ZeroZero (G) +2 | 0 (Figure 190o)

row four – M1:

- proportionM2ZeroM1 (F) -2 | -1 (Figure 190p)
- proportionM1ZeroM1 (C) -1 | -1 (Figure 190q)
- proportionZeroZeroM1 0 | -1 (Figure 190r)
- proportionP1ZeroM1 (D) +1 | -1 (Figure 190s)
- proportionP2ZeroM1 +2 | -1 (Figure 190t)

row five – M2:

- proportionM2ZeroM2 (G) -2 | -2 (Figure 190u)
- proportionM1ZeroM2 (D) -1 | -2 (Figure 190v)
- proportionZeroZeroM2 0 | -2 (Figure 190w)
- proportionP1ZeroM2 +1 | -2 (Figure 190x)
- proportionP2ZeroM2 +2 | -2 (Figure 190y)

When we closely inspect all the technical names we see that all of them have a “Zero” at the second position which represents *depth* and changes appear only in *width* and *height*. The two dimensional sheet of paper can be seen as the layer that we have chosen to iterate through them. We could have also use *depth* and leave *width* always as Zero. Or we might have decided to do both and have a lattice cube full of items but with a lot of duplicates.

When we look into Vision research we can see that there is some discussion about how well humans can judge aspect ratios and proportions. In some experiment this judgement is very error-prone and is used as an indicator that human are really bad at metric quantitative information overall. Most researchers agree that the performance improves when there are more depth cues present in a scene. The mainstream in Vision research tries to create experiments where only a single cue like “just curvature and not anything else” can be seen and studied in isolation. With Building Shape classification we don’t have this need to turn off all context information because the research goal is a different. Buildings are not context free and it is good to have context information like streets and horizon lines in the photographs .

Still we should at least take away the general notion from Vision research that humans are bad at this task. For instance this statement by Pizlo in a study about a monocular experiment: “but it is important to realize that _aspect ratio_ is only 1 of the 15 parameters that are used to characterize this 3D shape. All of the remaining 14 geometrical-characteristics of the 3D shape had no errors when viewing was monocular." (Pizlo *et al.*, 2014, p. 154)[150]. It might very well be that we as viewer know intuitively that our proportion judgement is error prone and maybe concentrate on other properties. Proportions are taught at universities as an important tool for aesthetics and it might be that when we spend a few minutes at a building we might recognize certain proportions and enjoy their composition. But here we use it as a simple tool to calculate similarities.

The table of five by five items in Figure Figure 189 should not be considered complete. Depending on the task at hand one could add additional rows with a “plus 3”, “plus 4” etc. For World Exposition pavilions this has been sufficient and maybe the whole first row could be omitted but that would have made the table less elegant. The Vision researcher Biederman is more radical and proposes: “three variations could be defined depending on whether the axis was much smaller, approximately equal to, or much longer than the longest dimension of the cross section” (Biederman, 1987, p. 124) . But one should take into account that Biederman concentrates at the first 100 milliseconds while we can assume longer viewing times for Building Shapes.

We can also reflect that our definition and use case of proportion differs from IL 22.[151] With the statement: "The form of an object is characterised above all by its proportions. 'Proportions' are the relationship between the dimensions (width/length/height)" (Otto, 1988, p. 22) the IL 22 team uses proportions to connect dimensions. A two dimensional surface does always have a non zero thickness[152], so does a one dimensional line. As our use case is much narrower then the IL 22 work, we are closer to the *three dimensional* objects of IL 22. We create variations and specializations of these three dimensional objects with the use of the golden ratio multiplier.

150 Underscores “_” added for emphasis

151 See “Dimension first; surface second” section in 5.4.2.

152 The non zero thickness is an important driver for the IL 22 work. It deliberately tries to have a classification system for organic and man made objects. “One and two-dimensional objects do, strictly speaking, not exist” (page 22). There is always mass and volume. IL 22 neglects the abstract geometric space.

8. Building Shape Syntax Tree

Chapter 6.6 gave an overview of the concepts which combined make up a Building Shape Syntax Tree. This chapter adds some background information and also incudes an exhaustive enumeration of all classification sets and their containing classification items which are used within a Building Shape Syntax Tree.[153]

8.1. Background

Composition of building shapes is a tool in the repertoire of architects and a system for building shape classification should try to handle it. The Vision[154] researcher Biederman[155] (see 5.3.2) touches composition in his *Geon* approach but concentrates on components. Of course Biederman does this in his research context of general human perception. Similar the architecture centric projects "IL 22 – Form" (see 5.4.2) and "Structural Design Aid" (see 5.4.3) acknowledge the importance of composition and offer some basic building blocks. The "Structural Design Aid" is more applied then the generic approaches from "IL 22 – Form" and Biederman's Geons. It tries to achieve a similar goal to this thesis: classification of buildings. We will see some influence from the work on *arrangement* from Loh in this chapter, for instance when discussing *Spacing* and *Orientation*.

We introduce the concept of Building Shape Syntax Tree to describe *composition* of building shapes.

In this thesis[156] *Syntax Tree* is used to describe a certain type and setup of building shape composition. It does not adhere either to the stricter definitions in Linguistics nor Computer Science.[157] The term was initially transferred from Linguistics. Rather then trying to also carry over the whole linguistic theoretical model, it is a transfer of

153 We will mostly refer to *Building Shape Syntax Tree* just as *Syntax Tree* in this and the remaining chapters. As there is less ambiguity then in interdisciplinary chapter 5.

154 In Vision research, composition is also recognized as an important aspect. It is mentioned in a major review paper of the domain. (Todd, 2004, p. 118)

155 In Vision research, Biederman is not alone on the position that *composition* is a tool to consider in analysis. Todd (2004) also briefly acknowledges this in a major review paper of his field (see chapter 5.3.3).

156 Meaning all chapters expect of the interdisciplinary chapter 5.

157 In Computer Science two prominent uses of "Syntax Tree" are *Abstract Syntax Tree* (AST) and the parser centric *Concrete Syntax Tree*. Computer Science, and especially *programming language* theory borrow a lot of vocabulary from Linguistics. This is an ongoing process. It can also be traced back to common theoretical foundations. E.g. in chapter 5.1.1 we discussed the linguistic work of Noam Chomsky. His 1957 publication "Syntactic Structure" is considered pivotal. But one year earlier he also published "Three models for the description of language" (1956), which is still a foundational classification in computer science.

technique.[158] The transfer is limited in scope, as it mostly focus on the idea to use a binary tree to store, process and reason about information. This is similar to the way Lerdahl and Jackendoff (1983) took Linguistics as an inspiration and source for techniques and thinking patterns in their analytical work of Music (see 5.2).

An alternative to the use of the word "Syntax" would be the term "Structure" which Lerdahl and Jackendoff (1983) (Jackendoff, 2009, p. 201) use to introduce "Prolongational Structure". Lerdahl and Jackendoff use this term on purpose to avoid the use of the term "Syntax". Therefore "Structure" is a convenient term for a research that describes a theory of music. But "Structure" is problematic in a research about architecture, because structure is often associated with various physical properties of buildings like load bearing. Transferring the term "Syntax" from a different domain allows us to easier distinguish between physical buildings and an information system.

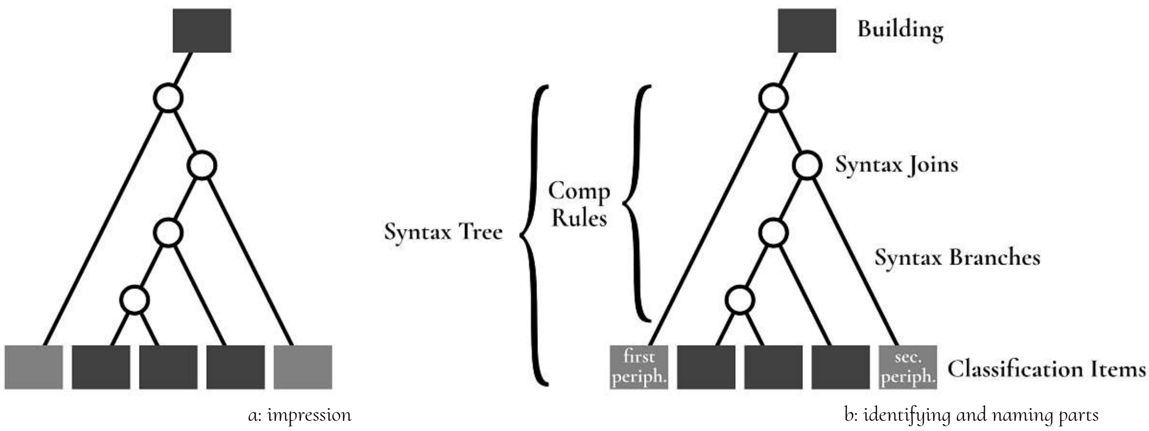


Figure 191: Visualisations of the binary tree data structure as used in this thesis. "first periph." is an abbreviation for "first Periphrase" and "sec. periph." for "second Periphrase". "Comp Rules" is a abbreviation for "Composition Rules"

Recursion is one of the properties that make the proposed Syntax Tree attractive for computation as well as human reasoning. We follow the definition: "in which the solution to each problem depends on the solutions to smaller instances of the same problem"(Graham *et al.*, 1994).[159] These properties make recursion a good tool to approach complex problem.

Generative Linguists like Chomsky (see 5.1.1) already utilised recursion starting in the sixties. They valued the simplification in data processing as well as the readability. Building upon recursion, Chomsky introduced a new visual notation in his discipline which enabled linguist to communicate and reason about syntax in a novel way. The mainstream view in Linguistics assumes that recursion might be exclusive to human language and distinguishes humans from animals. Other linguists like Jackendoff (see 5.1.2)

158 The alternative to the borrowing of the term "Syntax Tree" would be to invent a new word or use an abbreviation. Borrowing words from other domains is typical in a living language and in science.

159 In computer science and in this thesis we use the term *Recursion*. In mathematics, like in Graham`s definition, the term *Recurrence* is also widely used. In programming language recursion is one of the most important patterns to reduce complexity and perform complex computations with a manageable amount of source code.

argue that recursion also appears in human vision, task planing and music. Though absent from animals' communications systems, it can be found in visual cognition and task planing. For instance mammal animals have biologically very similar eyes to humans. One can assume that they process the information in a similar way. Animals also perform complex tasks, like lions hunting in a pack.

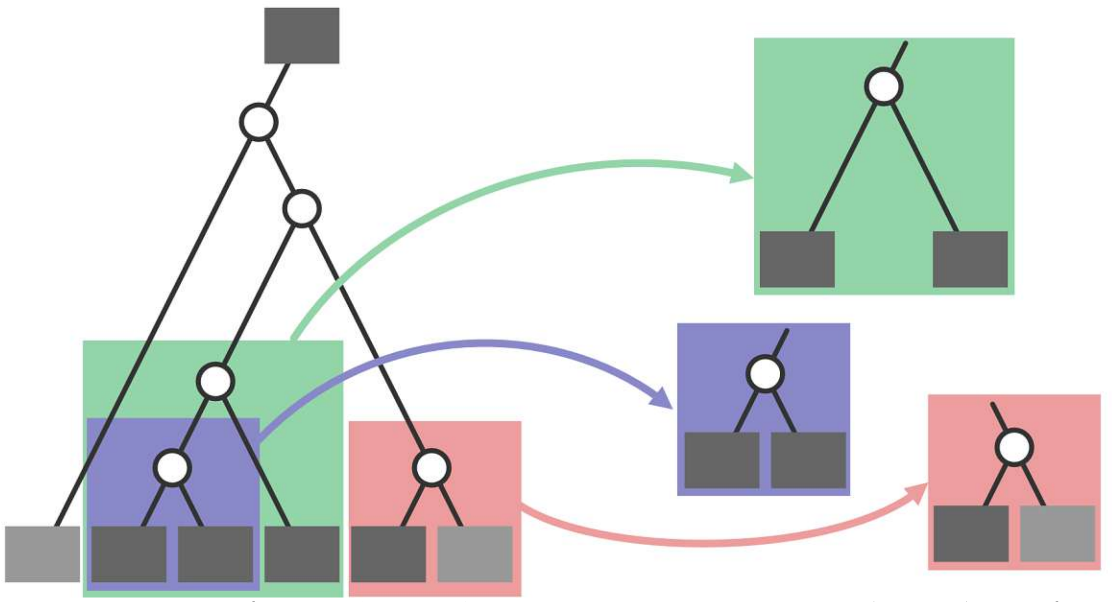


Figure 192: Visualisations of recursion fragments. While the whole tree might become complex, it is still composed of "self repeating" / "recursive" pattern. For visual simplicity the coloured visualisation only extracts three fragments while this tree actually contains five. Essentially the pattern repeats at each node that is represented as a white circle.

Figure 192 visualises the recursion in an idealised Syntax Tree. When the rules for recursion are well defined, then the system does not care about the size of an information data structure. A software system can treat the growing Syntax Trees in Figures 196, 197, 198 with the same source code and little additional effort. We also benefit from recursion when we compare building shapes with each other (see 9.7.2).

53 of the 80 World Exposition Pavilions have a Syntax Tree. 27 World Exposition Pavilions only consist of a single distinct building part. When a building consists of a single distinct building part with a single Periphrase it still has a Syntax Tree. It is just a very simple one. It can still be compared to more complex Syntax Trees that contain more then one part. The technical implementation uses a helper node between the root, representing the real building shape, and the Periphrase. The node is called a "NO OPeration" (NOOP) node and enables the software to compare this shape with shapes that have a composition of more then one part. The abbreviation NOOP is common in software development to describe behaviour like this.

The following subsections will discuss some details of Syntax Trees. This enumerations gives an overview of the three buildings which serve this discussion:

- Figures 193 and 196 - B5 - Expo 2010 Luxembourg Pavilion (Shanghai)
  The composition is special. One part surrounds an other one. The iconic part is actually smaller then the surrounding lower part which houses most of the exhibition (Alexander and Flagge, 2010). Because there are only two parts the Syntax Tree is small. It also uses some default classification items. Default items can be spotted as faded boxes in the bottom row, as well as by the use of dashed lines.

- Figures 194 and 197 - X2 - Expo 1967 Brewers Pavilion (Montreal)
  The flat cylindrical parts of the pavilions look similar to each other. We call this *self-similarity*. Self-similarity is handled by supplying two identical Periphrases and work with *Cardinality* and *significance*. Significance can be spotted by a circle icon with "two upwards arrows" at the node on the main axis. The Cardinality is cardApproximatly5. A cardinality of more then two triggers additional information about Variety and Size Randomness which makes the Syntax Tree a bit bigger. The Spacing is spacingPlanarOverlapPartial.

- Figures 195 and 198 - A4 - Expo 2010 Russia Pavilion (Shanghai)
  We will discuss the Russia pavilions in detail in chapter 8.3. Figure 216 shows a better readable version of the Syntax Tree.
  In the next subsection it is of interest that the iconic parts are twelve towers with self-similarity. They surround a larger unimposing exhibition hall. The Syntax Tree is large and contains two branches that merge into the main axis. Parts of the Syntax Tree are in a faded light grey while other are in a solid black. The greyscale gradient carries information about significance together with the already mentioned circle icon with the "two upwards/downwards arrows".

Figure 193: Aerial View
B5 - Expo 2010 Luxembourg Pavilion (Shanghai)

Figure 194: Aerial View
X2 - Expo 1967 Brewers Pavilion (Montreal)

Figure 195: Aerial View
A4 - Expo 2010 Russia Pavilion (Shanghai)

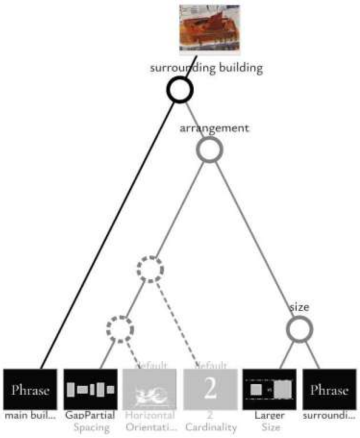


Figure 196: Impression of Syntax Tree
B5 - Expo 2010 Luxembourg Pavilion (Shanghai)

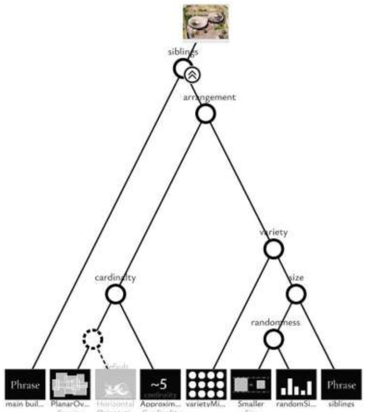


Figure 197: Impression of Syntax Tree
X2 - Expo 1967 Brewers Pavilion (Montreal)

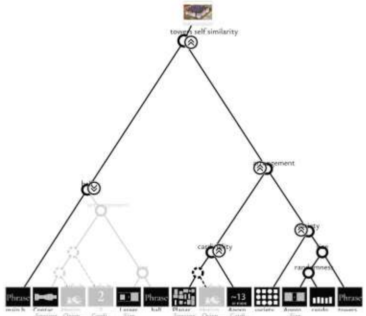


Figure 198: Impression of Syntax Tree
A4 - Expo 2010 Russia Pavilion (Shanghai)

We can see in Figures 196, 197 and 198 how the the Syntax Trees grow when the building shape composition gets more challenging. This might trigger two questions:

- Simplicity - Is this still simple?
- Subjectivity - Are all the chosen classification decision correct?

8.1.1. Simplicity versus ...

Simplicity is a positive ideal that one is told to aim for. On a first look – and ,aybe even on a second look – the Syntax Tree of the Russia Pavilion seems complex. This impression can be discussed from three different angles: novelty, local context and task context.

Simplicity versus Novelty

A new system is new. By proposing an alternative to describe building shapes which is different to a perfect digital 3D replica and free form text we are exposed to new ideas. But novelty does not by definition constitute complexity. The intuition of “absence of simplicity” might also be rooted in a lack of personal experience with what we present.

We can draw a parallel to linguistic science. Researchers that study natural language syntax are accustomed to work with binary tree representations of linear sentences for decades. It is a tool in their repertoire to get an analytic or computational task done. It does not mean that these researchers have given up writing nice linear sentences. They are interested in the components and can benefit from the hidden information once they extract it. Similar, in this thesis we use photographs of buildings and this is were we spend most of our exploration on. The Syntax Tree is just a novel and more structured documentation of what we have discovered.

The Syntax Tree is an *expert tool* which the people that perform the classification must understand. It is then an enabler for more user centric use cases like: "Rank some buildings by similarity to building X" (see 12.1). There the end user is not actively exposed to the Syntax Trees but rather photographs and percent values.

Simplicity versus Local Context

In the Introduction of this thesis we try to show in the Figure pairs 1 & 2, 3 & 4 and 5 & 6 that local context can imply simplicity which vanishes when the context changes. Similar we can look at the three pavilions in Figures 196, 197 and 198. We can claim that the proposed composition is to complex.

We will perform a small thought experiment. Please be aware that we are focusing here on the *composition*. So we must imagine that the distinct building parts look very similar. Think of boxes. We will try to describe the composition in free form text, in a way that is sufficient to distinguish the three building shape compositions. Of course this is just one of many possible approaches that freedom of natural language allows:

(1) One part is surrounded by the other one. (Luxembourg pavilion)

(2) Many parts stacked into each other. (Brewers pavilion)

(3) Many parts surround one part. (Russia pavilion)

The text statements already utilise the linear order of the sentence for *significance*. For instance statement (3) can be written in at least two ways. The variations make different parts more significant. This information already hints which part will be on the main axis.

(3) Many parts surround one part.

(3`) One part is surrounded by many parts.

We need to chose between (3) and (3`). Imagine to tell a friend to meet at the Russia pavilion, but you forgot the nation. Would you tell him to meet at the pavilion that houses its exhibition in a large cubic hall, or would you describe the surrounding towers?

Lets annotate statements (1), (2) and (3)

(1a) (One part)$^{\text{quantity}}$ is (surrounded)$^{\text{arrangement}}$ by the (other one)$^{\text{quantity}}$.

(2a) (Many parts) ^{quantity} (stacked into)^{arrangement} each other.

(3a) (Many parts) ^{quantity} (surround)^{arrangement} (one part)^{quantity}.

We can observe that we created two implicit classification sets:

- *Quantity*, with the three classification items: “1”, “2” and “many”.
  “2” is derived from the sum of “one […] by the other one” from statement (1a).
  In statement (3a) we can see that we also used quantity twice. This implies two groups which are distinct.
- *Arrangement*, with the classification items: “surrounds” and “stacked into”.
  The addition “each other” is already information about *self-similarity*.

We created two implicit sets because one is not sufficient to disambiguate the Russia pavilion from its peers:

- *Quantity*: Lets meet at the pavilion that is made from many parts.
  (Russia and Brewers)
- *Arrangement*: Lets meet at the pavilion where some parts surround other parts.
  (Russia and Luxembourg)

We can imagine how our mind can do this semantic operation on the fly, and has no problems to distinguish between quantity items and arrangement items. We can assume that it did not just created five unsorted tags: “2”, “surrounds”, “many”, “stacked into”, “1”.

We can also see the power of natural language. The term “surrounds” carries a lot of information. “Surrounds” is even a concept that the proposed classification system in this thesis can not handle well. It would most likely require one or two new *orientation* classification items like *orientationInside* and *orientationOutside*. Potentially with a Matryoshka doll like icon.[160] It implies a centre and a spacing relationship between the surrounded part and the surrounding part(s). The *arrangement* items in statements (1), (2) and (3) would actually come from two classification sets in the proposed system: *Spacing* and *Orientation*.

The result of the small thought experiment might differ for each human. This subjectivity will be discussed later in 8.1.2. The experiment should have exposed that we intuitively encode semantic and classification structure in our day to day tool of *natural language*, even though it does not surface immediately.

160 Maybe it additionally would require symmetry information as described in chapter 8.4. It also overlaps with the Feature classification item featureLowpointCourt from the Periphrase.

Simplicity versus Research Task Context

We can state that our *research task* is constrained by a closed world assumption driven by the 80 World Exposition pavilions. The proposed system in this thesis is tailored towards the building shape classification of these 80 buildings. A system that covers 160 pavilions might look slightly different. A system to classify 80 football stadium would most likely require only a subset of all classification sets and classification items proposed here. Though football stadium classification would benefit from symmetry information like described in 8.4. A system that deals with buildings in an urban context, were firewalls are present and large parts are not visible or accessible, might require classification sets which are not obivous for World Exposition pavilions.

Even though the system is *tailored towards* the 80 World Exposition pavilions it does not mean that it is reduced to a minimum to just cover the 80 buildings. For instance the *Proportions* classification set in the Periphrase contains many classification items that are unused. Still they are included to make the set coherent. Similar the Syntax Tree classification set *Spacing* contains unused items as it covers orthogonal concerns. The smaller classification sets *Relative Size*, *Size Randomness* and *Variety* can be considered linear with a gradient of values, so skipping unused values would make them less coherent.

In our local context 66.6% of all compositions use "surrounds". But by coincident the Luxembourg pavilion and the Russia pavilion are the only pavilions within the 80 selected pavilions where one distinct building part surrounds an other one.[161] This sums up to 2.5%. We can see that it is the responsibility of the creator of the classification system to decide if it is worth to include "surrounds" into the system. Two buildings use it. Is this sufficient, or does it creates to much noise?

To some extend we can use empirical data to test if the decisions of the creator of the classification system are sound. We can omit certain parts and see if the whole system still perform acceptable. This is something we will see in chapters 12.2, 12.3 and 12.4. were we turn off features and whole classification sets. Though we can not investigate if something is valuable when we did not add it in the first place, like "surrounds".[162]

In a task context of 3 pavilions we might decide that the use of hierarchical binary trees is over-engineering, and that "free form tagging" or "tagging with at least one item of each of the two classification sets" is sufficient. But when we double the amount to 6, 12,

161 Though there are some more examples where one or multiple distinct building parts surround a void. Like in a court or a plaza.

162 It is also challenging to do these exclusion tests on a fine grained classification item level, as we need a substitute item, or a decision that a substitute item can be omitted. To have this decision automated one could leverage named relationship (see chapter 9.3). A setup where we skip single classification item is technically possible and could be performed manually for a few distinct items, but it exceeded the scope of this thesis and was not performed.

24, 48... pavilions the situation changes. The need for additional classification sets and a system to connect them – the hierarchical binary tree – might increase. Also the goal of our classification is not the description of one building shape, but rather have a foundation to build upon and have applications like building shape similarity (see chapter 9).

8.1.2. Subjectivity

The curation of the proposed classification sets, as well as the use of them to create classification models for the 80 World Exposition pavilion are the work of the author of this thesis. We will call this individual *single author* in this subchapter. As all research this thesis will benefit:

- On a theoretical level - from scrutiny from peers that are interested in the domain. Does the proposed system cover the concerns and is it coherent?
- On a performance level - by comparing it with competing approaches. These approaches might be traditional, or come from more contemporary trends like machine learning. Does the proposed system deliver benefits?
- On an editorial level - from active use and feedback by further individuals who create more classification models for more World Exposition pavilions. It might be even more valuable when competing Syntax Trees and Periphrases for the existing 80 World Exposition pavilions can be created, compared and discussed.
- On an applied level - by empirical feedback from participants if the result match their individual expectations. A foundation for empirical work is already present in chapters 11 and 12. But the current empirical work treats the task as an *inverse problem*. Empirical verification of the model would be a *direct problem*.[163]

When we look at more complex Syntax Trees like the one from the Russia pavilion (Figure 198, Figure 216), we can see that a lot of decisions are taken by the single author, which are done by best intent, but are still subjective. Are all of these small classification decision correct? Why to prefer a certain classification item over an other? This can diverge either into a valuable case study discussion, as other authors might have more insights into the design of a certain building, or a philosophical discussion, or into an empirical data gathering and analysis project.

The current proposed system does try to help with the ambiguity, by providing these techniques:

- The Syntax Tree does not enforce a certain tree structure.

163 See statement (1) in chapter 8.4 where we briefly discuss the Theory of Inverse Problems.

- *Weak References* (see chapter 9.3) mitigate the binary decision of the selection of one classification item over an other from within a classification set.
- *Strong independence* (see chapter 9.2) when we try to use the system to compare building shapes to each other, which is close to a naive Bayesian.
- Statistical comparison against empirical data. Certain proposed features are turned on and off and their impact can be observed and judged. This is done in chapters 12.2, 12.3 and 12.4.

We will now discuss the first item from above list, while the other are discussed later in the referenced chapters.

When we look through the 53 Syntax Tree models in Appendix A (19.1), we see repeating patterns. For instance the *Spacing* item is augmented with *Cardinality* and *Orientation*. Also at many places *Spacing* merges higher into the tree then *Relative Size*. But these are repeating patterns by the single author. They are not enforced by the theory and the software implementation. A different author might arrange the items in a different branching, and it would still be within the system.

Of course there is best intention by the single author why some pattern repeat. For instance the repeating group of *Spacing*, *Orientation* and *Cardinality* resulted from a breakup of an earlier draft with a bigger *Arrangement* classification set. Orthogonal concerns were identified and it appears cleaner to have separate classification set for it.[164]

Some classification is only added due to a logical consequence. For instance when there are more the two distinct building parts in the composition it makes sense to document the *Size Randomness* and *Variety* of Relative Size. When there there are only two distinct building parts there is no need to document it.

We can observe that the single author utilized the flexibility of the Syntax Tree and added two arrangement branches in “D2 - Expo 1967 Africa Group Pavilion (Montreal)” (see Figures 199, 200 and 202) and “D5 - Expo 2010 Cases Theme Pavilion (Shanghai)” (see Figures 201 and203).

Figure 199: D2 - Expo 1967 Africa Group Pavilion (Montreal)

Figure 200: D2 - Expo 1967 Africa Group Pavilion (Montreal)

Figure 201: D5 - Expo 2010 Cases Theme Pavilion (Shanghai)

164 We will see a similar breakup into multiple smaller classification sets when we discuss symmetry in chapter 8.4.

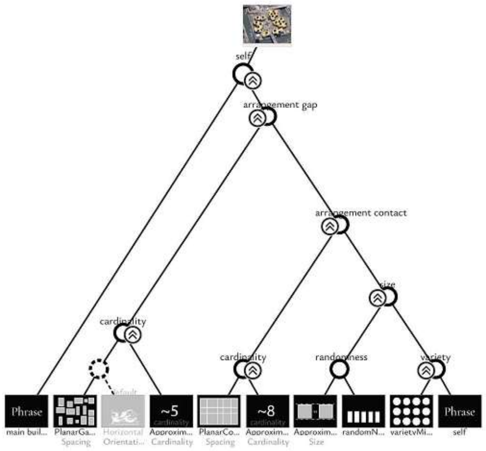


Figure 202: D2 - Expo 1967 Africa Group Pavilion (Montreal)
Impression of the Syntax Tree with two arrangement branches

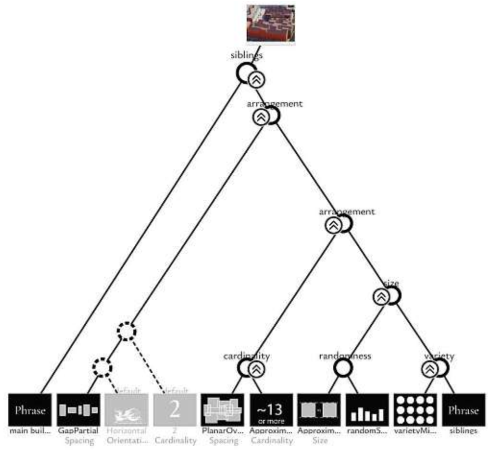


Figure 203: D5 - Expo 2010 Cases Theme Pavilion (Shanghai)
Impression of the Syntax Tree with two arrangement branches

8.2. Syntax Tree Classification Sets

8.2.1. Spacing

The *Spacing* classification set describes how two or more distinct building parts are positioned relative to each other. The set does not include cardinality nor orientation information. So it is not determine if the building parts are stacked or lie next to each other.

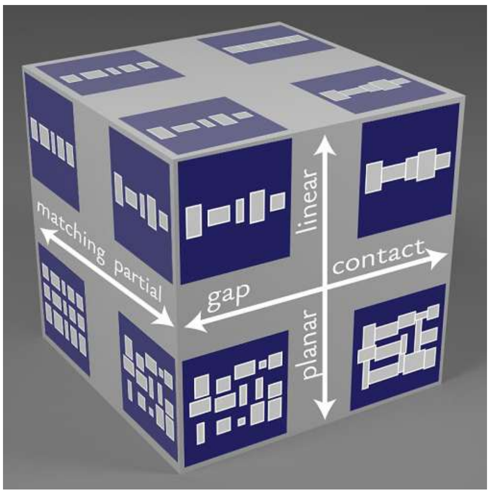


Figure 204: Visualisation of the connection between items in the spacing set. Front side.

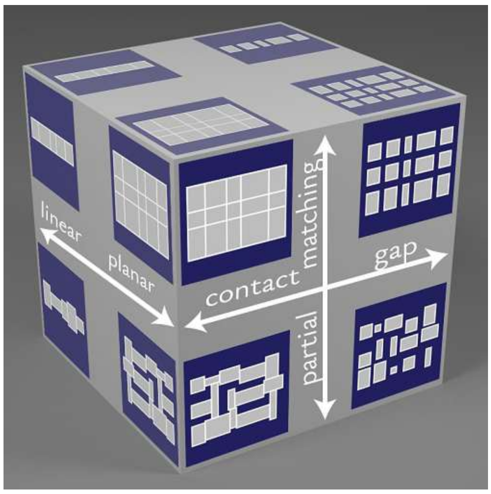


Figure 205: Visualisation of the connection between items in the spacing set. Opposite side.

There are three attribute groups that structure the items. Figure 204 and Figure 205 can be seen as two opposing sides of a cube with connections in between. The axis are:

- gap vs. contact – The horizontal attribute describes if the building parts have space in between them or if they touch each other, typically at a common wall or floor.

- matching vs. partial – The vertical attribute describes if the building parts have faces that point towards each other that would match in size or if there is only a partial area.
- linear vs. planar – The depth describes if there is a linear arrangement or a planar one. Planar variants shown in the second Figure 205. In theory there could be a third attribute here as well which would cover *spatial* arrangement but it was omitted.[165]

Beside of the 2 by 2 by 2 cube described above we can take the already mentioned pair of *gap vs. contact* and expand it to a group of four with: gap vs. contact vs. overlap vs. blob. This can be seen in Figure 206 for a linear arrangement.

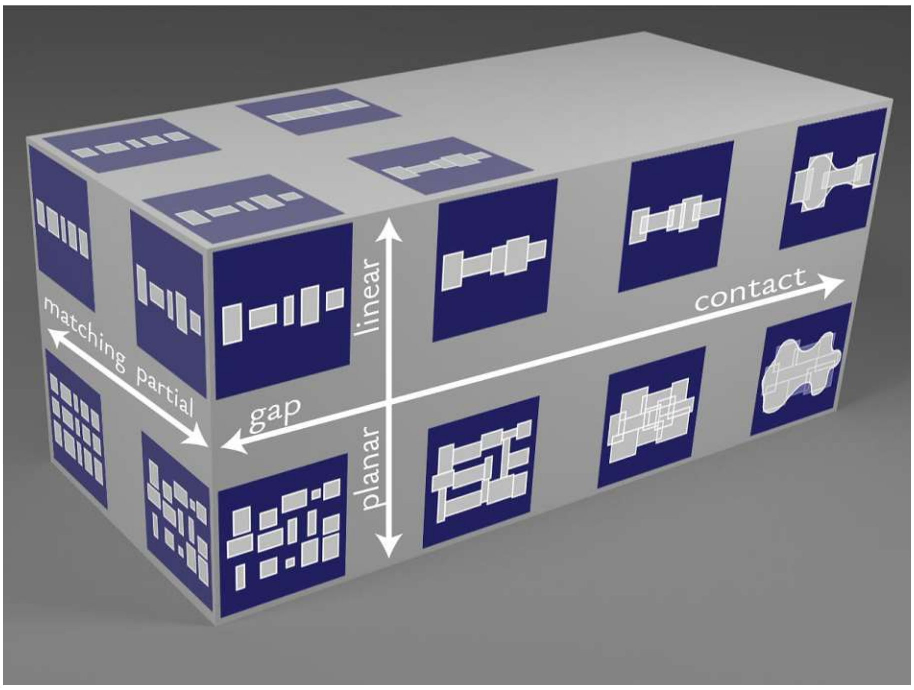
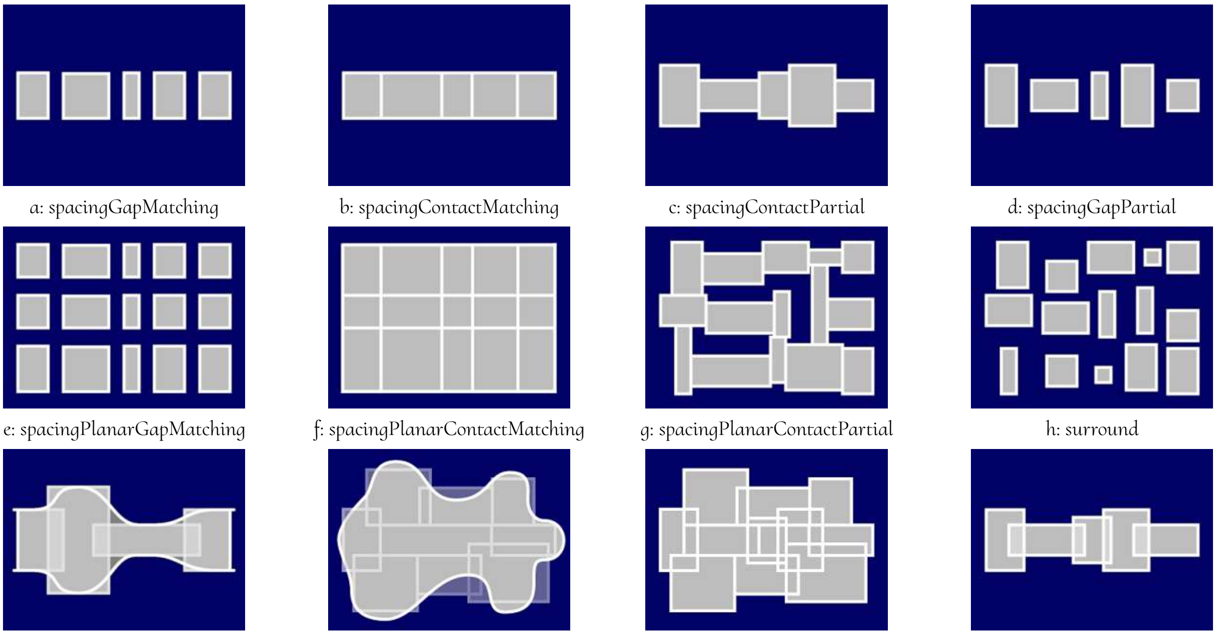


Figure 206: Visualisation of the connection between items in the spacing set. Longer box. The visualisation also makes the weak references easier to follow. They are documented in Appendix B (19.2).

165 Two of the few buildings that could have benefited from a spatial arrangement are the Netherlands pavilion in Expo 1970 Osaka and the Netherlands pavilion in Expo 2010 Shanghai. For both cases the planar attribute was used instead. The Netherlands pavilion in Expo 1967 Montreal is also a bit similar but more planar. The Netherlands pavilion in the Expo 2000 Hannover was vertical. So we might start to identify a fashion trend in Dutch pavilion design.



a: spacingGapMatching b: spacingContactMatching c: spacingContactPartial d: spacingGapPartial
e: spacingPlanarGapMatching f: spacingPlanarContactMatching g: spacingPlanarContactPartial h: surround
i: spacingBlob j: spacingPlanarBlob k: spacingPlanarOverlapPartial l: spacingOverlap

Figure 207: Classification set: Spacing (all items)

We can enumerate the technical keywords by first looking at linear attributes linear matching:

- spacingGapMatching (Figure 207a)
- spacingContactMatching (Figure 207b)

linear partial:

- spacingGapPartial (Figure 207d)
- spacingContactPartial (Figure 207c) this is the default item
- spacingOverlap (Figure 207l)
- spacingBlob (Figure 207i)

And then in the same order the planar attribute planar matching:

- spacingPlanarGapMatching (Figure 207e)
- spacingPlanarContactMatching (Figure 207f)

planar partial:

- spacingPlanarGapPartial (Figure 207h)
- spacingPlanarContactPartial (Figure 207g)
- spacingPlanarOverlapPartial (Figure 207k)
- spacingPlanarBlob (Figure 207j)

8.2.2. Cardinality

The set is used to identify the number of distinct building parts that are involved in the composition. Cardinality usually augments Spacing.

Cardinality is a mathematical term to refer to the number of elements in a set. Quantity, amount or count are synonyms for cardinality. The decision to borrow the word *cardinality* from the more formal discipline mathematics rather then a word like *quantity* is a pragmatic one. The term *quantity* is very generic and its use is broad. For instance we use it to discuss qualitative versus quantitative properties. The rare term *cardinality* stands out and is only used as a name for the set. Still we redefine it as *building shape cardinality* and lift many of the formal constraints of *mathematical cardinality*.

The pattern that defines which numbers are used is the Fibonacci sequence: 1, 2, 3, 5, 8, 13. The choice for the Fibonacci sequence is similar to the use of the golden ratio in the proportions classification set. The Fibonacci numbers expand in a way that makes it easer for a person to chose a number. Contrary a sequence of the factor of 2 like 1, 2, 4, 8, 16 makes selection harder and we would omit the number 3.[166]

The Fibonacci sequence leads to gaps and the integer numbers 4, 6, 7, 9, 10, 11, 12 and all number from 14 and higher are missing. Therefore starting with the number 5 there is a hatch with the word *approximately*. The missing of the number 4 is a bit unfortunate because it is common in architecture. From a similarity calculation point of view there should be less difference with a building with for instance 4 high points and 5 high points. For higher cardinalities it is also sometimes argued that humans can grasp number up to approximately 5 without much effort and counting, while bigger numbers require more mental effort and often counting. We have an innate cognitive capability for small number but start to approximate higher numbers.

The highest element is the “approximately 13” the next Fibonacci number would be 21, but for building shape classification these cardinalities can be collapsed to a “13 or more”.

The proposed classification set can be interpreted as an applied middle ground between mathematics *discrete elements* on the lower bound and linguistic *mass nouns* on the upper bound.

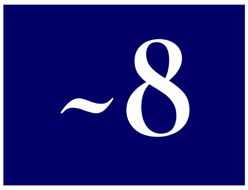
166 Fibonacci numbers are often used in business task estimation in software engineering for exactly this reason. Software developer should decide if the complexity of a given task is bigger then another one. By using the Fibonacci sequence, it is easier to say “it is bigger” instead of arguing “well the complexity is bigger but actually not double the size, … is there something in between?”

a: card1

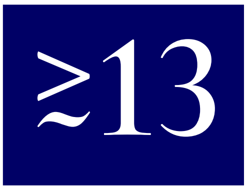
b: card2

c: card3

d: cardApproximatly5



e: cardApproximatly8



f: cardApproximatly13OrMore

Figure 208: Classification set: Cardinality (all items)

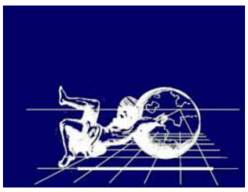
The enumeration of the items and their technical keywords are as follows:

- card1 (Figure 208a)
- card2 (Figure 208b) this is the default item
- card3 (Figure 208c)
- cardApproximatly5 (Figure 208d)
- cardApproximatly8 (Figure 208e)
- cardApproximatly13OrMore (Figure 208f)

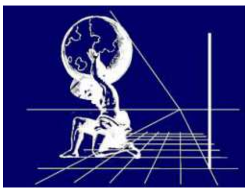
8.2.3. Orientation

Orientation is an extrinsic property and it is bound to gravity and the ground plane. It describes how a branch in the Syntax Tree is related to gravity. Similar to the Periphrase *Proportions* classification set there is no distinction between front, left side, right side and back. Orientation usually augments Spacing.

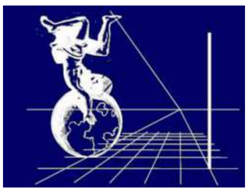
The most interesting member is orientationVerticalDown which is an upside down arrangement. This hints that the dominant distinct building part is on top of the second one. This is related to the Periphrase *Tilt* classification set and the conceptual relation is already disused there.



a: orientationHorizontal



b: orientationVerticalUp



c: orientationVerticalDown

d: orientationDiagonal

Figure 209: Classification set: Orientation (all items)

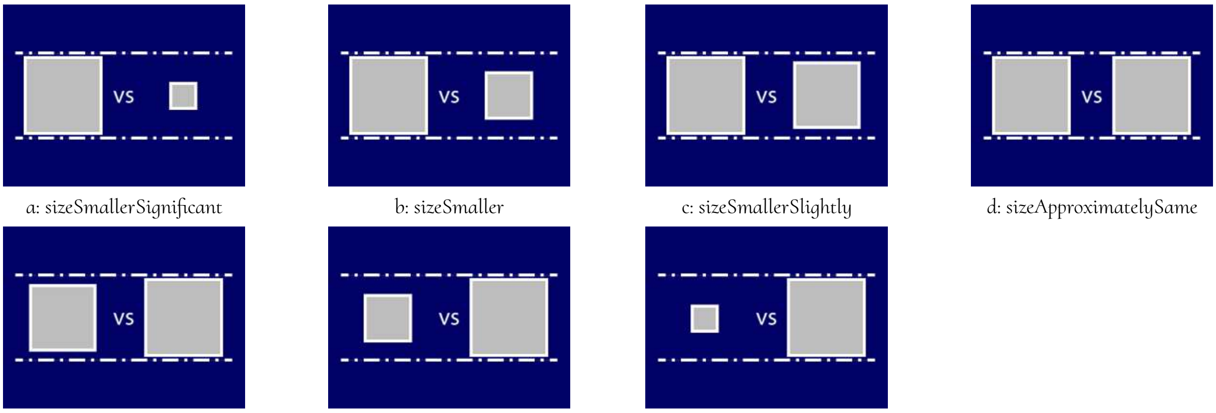
There are only four items in this classification set:

- orientationHorizontal (Figure 209a) this is the default item
- orientationVerticalUp (Figure 209b)
- orientationVerticalDown (Figure 209c)
- orientationDiagonal (Figure 209d)

8.2.4. Relative Size

Relative Size of the *dominated* distinct building part(s) to the *dominating* building part. Branches in a Syntax Tree describe the merging distinct building part in relation to the main distinct building part. An assignment for a smaller annexe to a bigger main building would be: sizeSmaller

As the architecture importance does not need to be bound to size it might very well be that a small expressive distinct building parts sits on a much bigger base which contributes less to the identity of the whole building. For instance the iconic roof top of E2 - Expo 2010 China Host Pavilion (Shanghai)[167] sits on a large base which gets little attention.



a: sizeSmallerSignificant b: sizeSmaller c: sizeSmallerSlightly d: sizeApproximatelySame

e: sizeLargerSlightly f: sizeLarger g: sizeLargerSignificant

Figure 210: Classification set: Relative Size (all items)

There is a quantifier attribute that ranges from: slightly, normal (which is omitted in the technical keyword) to significantly.

The enumeration starts with the more common smaller items and ends with the larger.

- sizeSmallerSignificant (Figure 210a)
- sizeSmaller (Figure 210b)
- sizeSmallerSlightly (Figure 210c) this is the default value

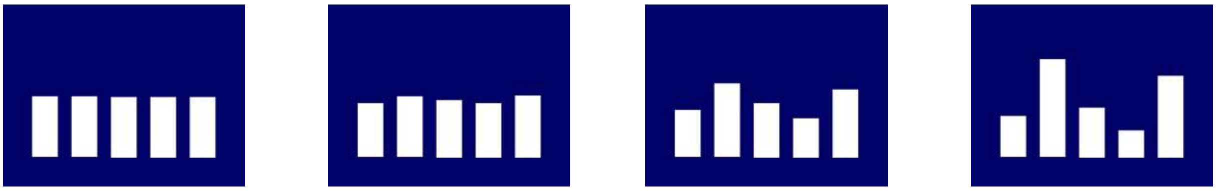
167 See chapter 10.4 for six photographs of E2 - Expo 2010 China Host Pavilion (Shanghai). See also 6.1 where we discuss the pavilion and its distinct building parts as well. Appendix A (19.1) also has nine photographs.

- sizeApproximatelySame (Figure 210d)
- sizeLargerSlightly (Figure 210e)
- sizeLarger (Figure 210f)
- sizeLargerSignificant (Figure 210g)

8.2.5. Size Randomness

When Cardinality is equal or greater three then we can also identify Size Randomness of Relative Size.

For instance when a dominant distinct building part is surrounded by four smaller distinct building parts they might all be of the same size or they might have differences in size. Size Randomness usually augments *Relative Size*. Because it applies only to composition with at least three parts there is no default value that is automatically added by the software.



a: randomNone b: randomMinor c: randomSome d: randomSignificant

Figure 211: Classification set: Size Randomness (all items)

There is a quantifier attribute that ranges from: none, minor, some, significant.

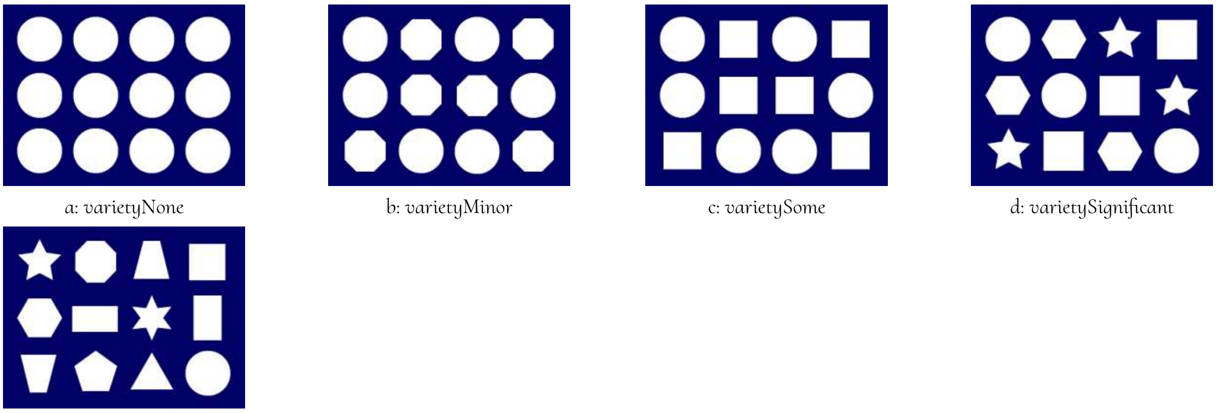
The items start with the negation and then build up by the quantifier attribute:

- randomNone – describes the absence of any randomness and all item are of approximately same size (Figure 211a)
- randomMinor (Figure 211b)
- randomSome (Figure 211c)
- randomSignificant (Figure 211d)

8.2.6. Variety

Variety is related to *Size Randomness* and also applies when the *Cardinality* item is equal or greater then three. It is not concerned with size but rather with the uniform or variance in the building shape. The building shape of distinct building parts can be related in their architecture style and therefore be represented with the same Periphrase but still each one can look geometrically different.

A4 - Expo 2010 Russia Pavilion (Shanghai) is a good example use of Variety. The Russia Example is discusses in 8.3 with multiple Figures 213, 214, 215, 217, 218 and 219 showing the tower structures that contain Variety.



a: varietyNone b: varietyMinor c: varietySome d: varietySignificant e: varietyFull

Figure 212: Classification set: Variety (all items)

There is a quantifier attribute that ranges from: none, minor, some, significant and full. Because it applies only to composition with at least three parts there is no default value that is automatically added by the software.

The five items are:

- varietyNone – all merging distinct building parts look identical (Figure 212a)
- varietyMinor (Figure 212b)
- varietySome (Figure 212c)
- varietySignificant (Figure 212d)
- varietyFull – all merging distinct building parts look different but can be descried with the same Periphrase. This items is mostly theoretical and might be true for *blob like* building shape compositions. (Figure 212e)

8.3. Example Expo 2010 Russia Pavilion

We have already discussed the Syntax Tree of the Kaleidoscope in chapter 6.6.5. The Kaleidoscope is a good introduction building, because it has simple Periphrases as well as a simple Syntax Tree. We have seen a few impressions of other Syntax Trees in the Background chapter 8.1. We will discuss more examples in chapter 10. A full listing of all 53 created Syntax Trees can be found in Appendix A (19.1).

We will use this section to discuss one further example in detail: A4 - Expo 2010 Russia Pavilion (Shanghai). We have chosen this pavilion because:

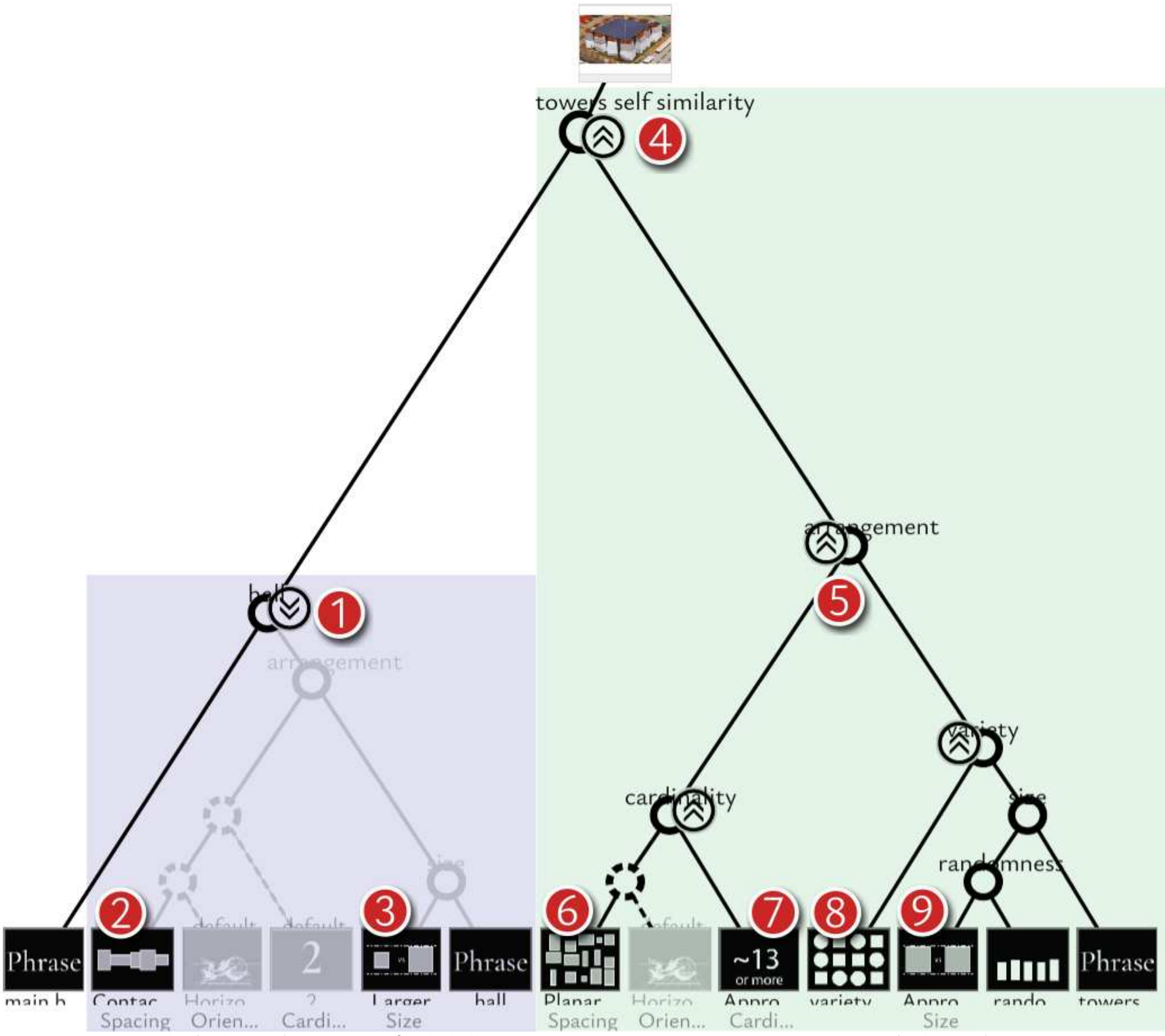
- It is a good show case for the six classification sets introduced for Syntax Trees.
- It has a challenging composition: Twelve expressive tower structures surround a simple hall.
- Because there are *twelve* towers we will see classification sets like *Variety* and *Size Randomness*.
- The twelve towers have a common visual language. This will give us the opportunity to discuss *self-similarity*.

For better correlation, we will keep three photos (Figures 213, 214 and 215) and the Syntax Tree on a single print page in Figure 216 . The Syntax Tree is annotated with red circles that are referenced in the following text sections like: “(4)”. We will call the hall “exhibition hall” and the the iconic expressive tower structures, just “towers”. The print page after will have another three photos (Figures 217,218 and 219) and a diagram of the Periphrase of the tower in Figure 220, as well as the simpler Periphrase of the exhibition hall in Figure 221.


Figure 213: A4 - Expo 2010 Russia Pavilion (Shanghai) Aerial View

Figure 214: A4 - Expo 2010 Russia Pavilion (Shanghai) Pedestrian View


Figure 215: A4 - Expo 2010 Russia Pavilion (Shanghai) Details View



Blue background: Syntax Tree for the hall

Green background: Towers

Figure 216: A4 - Expo 2010 Russia Pavilion (Shanghai), annotated Syntax Tree


Figure 217: A4 - Expo 2010 Russia Pavilion (Shanghai) Satellite View


Figure 218: A4 - Expo 2010 Russia Pavilion (Shanghai) Pedestrian View Day


Figure 219: A4 - Expo 2010 Russia Pavilion (Shanghai) Pedestrian View Night

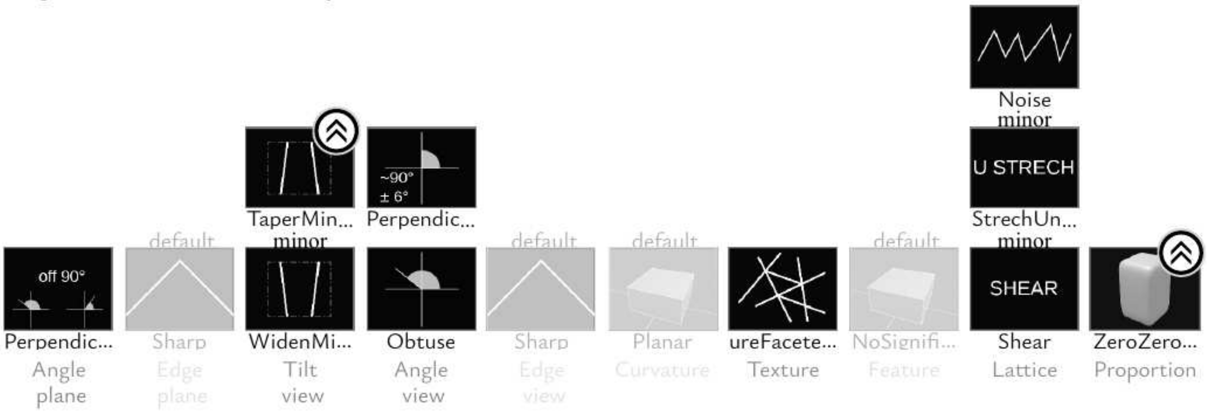


Figure 220: A4 - Expo 2010 Russia Pavilion (Shanghai), Periphrase of one tower

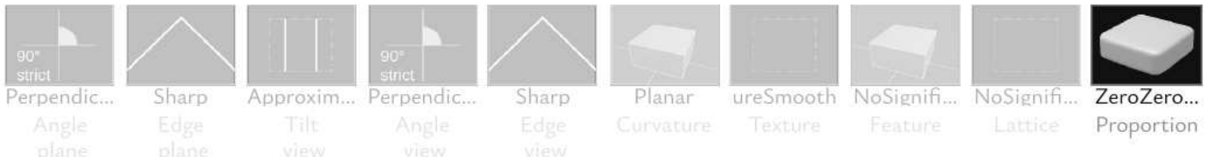


Figure 221: A4 - Expo 2010 Russia Pavilion (Shanghai), Periphrase of the exhibition hall

8.3.1. Syntax Tree of the Russia Pavilion

The rational behind the Syntax Tree for the Russia pavilion is: The author decided that the, by volume smaller, tower structures are the significant Periphrases. The bigger unimposing hall is of minor significance. Even though it houses most of the exhibition, it is hardly visible from a pedestrian view point. To handle this situation there are three Periphrase nodes in Figure 216:

- The left Periphrase in Figure 216 describes a single iconic tower. The Periphrase slots of the tower are in Figure 220.
- The middle Periphrase (blue subtree in Figure 216) describes the unimposing exhibition hall. The Periphrase slots of the exhibition hall are in Figure 221.
- The right Periphrase (green subtree in Figure 216) describes again a single iconic tower. Its Periphrase is equal to the most left Periphrase. This is the pattern to model *self-similarity*. The Periphrase slots of the tower are again in Figure 220.

Currently *self-similarity* is handled by supplying two equal Periphrases and work with *significance* and *Cardinality*.[168]

Significance of self-similarity can be spotted by a circle icon with "two upwards arrows" at the node on the main axis (4). Another visual hint is, that significant branches use a solid black colour for theirs lines and circles. Parts of the Syntax Tree are in a faded light grey while other are in a solid black. The greyscale gradient carries information about significance together with the already mentioned circle icon with the "two upwards/downwards arrows". The implications of making the self-similarity branch *significant* are two fold:

- During building shape comparison values from both Periphrases add to the final result and therefore increase the amount of "points" given for a Periphrase item like textureFacetedIrregular.
- The composition becomes more important as well.

Cardinality of self-similarity tries to model the quantity of towers that we see. It is *one* tower on the main axis; the node to the most left. Plus "*approximately 13*" more towers from the self-similarity branch (7); the node to the most right.

We will first discuss the exhibition hall and then move over to the towers.

Exhibition Hall

The Syntax Tree branch of the exhibition hall has a light blue background in Figure 216 and is located on the left.

The Periphrase of the exhibition hall is a good example of the use of default implicit classification items. It contains a single explicit slot value of proportionZeroZeroM2. Also two of its four Syntax Tree classification items are default items. The *orientation* and *cardinality* slots are faded and the lines and circle nodes are in dashed visual style.

(1) The author of the classification decided that the exhibition hall is of minor significance for the building shape of the whole building. This is reflected in the "two downwards arrows" at node (1). Also the lines and circles are faded out in a lighter grey.

(2) The *Spacing* of spacingContactPartial is actually the same as the default value. In theory it could be left out. The author still applied it to the Syntax Tree. This documents that it was actively discovered and makes it explicit. This will also lead to a slightly higher contribution when comparing Syntax Trees later in chapter 9. Please remember the discussion about "arrangement 'surrounds'" in chapter 8.1.1. We opted to skip the definition of 'surrounds' therefore this information is missing.

168 There have been alternative patterns in early state of the research project, but this implicit modelling of self-similarity simplifies the data documentation and the data processing.

(3) The *Relative Size* of sizeLarger is interesting, because it documents that even though this distinct building part of the exhibition hall is larger in volume it is of less significance.

Towers

The Syntax Tree branch of the towers has a light green background in Figure 216 and is located on the right.

(4) The branch of the towers merges higher into the main axis then the exhibition hall branch. This indicates that it is more important.[169] The branch documents self-similarity. We have discussed self-similarity earlier.

(5) The arrangement[170] sub-branch merges higher then the *Variety* and *Relative Size* sub-branches. This indicates that it is more important.[171] The node (5) also contains a significance attribute. So the contributions during comparison with other pavilions from the arrangement subbranch are preserved.

(6) The *Spacing* classification item is spacingPlanarGapPartial it is the closest available to match the arrangement of the twelve towers to each other.

(7) The *Cardinality* is cardApproximatly13OrMore. This is the closest match to the actual quantity of 12 towers. As we will see in chapter 9, the contribution of a classification item in a Syntax Tree degrades in a logarithmic fashion by default. Therefore we see significance "two upwards arrows" all the way between the cardApproximately13 up to the main axis to retain most of the contribution during comparison with other pavilions.

(8) The *Variety* is varietySome and it is marked with a significance attribute. The design team of the Russia pavilion put in effort to not repeat the same tower over and over again, still they use a similar design language. Even when we would have twelve Periphrases, one for each tower, these Periphrases would be *equal* or *nearly equal*. Here at the composition level we can document that there is actually some variety.

(9) The *Relative Size* of the towers, compared to the single "main axis tower" is sizeApproximatelySame. There is some *Size Randomness* of randomMinor of the *Relative Size* which is documented in the dominated sub-sub-branch.

169 This convention holds true, but is only present in theory. In theory the size of a Syntax Tree is unlimited. During creation of the data nearly always *significance attributes* have been added. In the software implementation there is currently no special treatment – and no real need yet – of two branches of the same significance being calculated differently. The human added *significance attributes* does provide this different treatment at the moment. Of course this might change in a data set with more then 80 buildings.

170 The term arrangement is a title for the grouping of spacing, orientation and cardinality. When we would be strict, it is the spacingPlanarGapPartial *subbranch.*

171 See footnote two before.

8.3.2. Expansion and Reduction

One of the attractive properties of Lerdahl and Jackendoff's approach to *prolongational reduction* is the possibility to reduce a piece of classical music to less and less notes, while preserving a significant amount of the identity of the melody. (see Figure 13 in chapter 5.2). This is the inspiration for the following experiment.

We will perform a second small thought experiment.[172] Please be aware that the following sentences are just one of many possibilities to describe the observed facts and each human might structure them slightly different. This is the power of natural language. We will "construct" sentences that we will slowly expand. We will handle Periphrase as well as Syntax Tree information. A human would most likely not distinguish between them actively. As discussed in subchapter 8.1.1 we assume that there are many pavilions. As this is a thought experiment, imagine an exhibition with one thousand pavilions.[173] Again imagine that we have forgotten that this is the Russia pavilion and we try to tell a friend how the pavilion looks like, so we can meet there.

We will build up a sentence in stages. We will underline the new information. In statement (8) we will restructure the phrases to make them read better in a natural language. We will colour code the phrases in the statements:

- Periphrase of one tower in black font colour.
- Compositions information of the towers will be in green.
- Composition information of the exhibition hall will be in blue.
- (Periphrase of the exhibition hall is so small that we keep it blue as well.)

Green and blue correspond to the background colours in Figure 216.

"Let's meet at..."

(1) The pavilion with towers.

Towers are significant. The plural already indicates that there are multiple towers so there will be building shape composition and therefore Periphrases and a Syntax Tree.

In natural language towers already transport the implicit information that the towers have a gap between each other. This constrains already the choices in Spacing (Figure 207)

172 First small thought experiment is in chapter 8.1.1.

173 When we add up the pavilions from all World Expositions we are at the scale of a few thousand pavilions. When we roughly estimate that there are 20 World Exhibitions and each has 100 pavilions then we are already at 2000 pavilions. During a review phase 610 pavilions have been candidates for further insight (see Figure 62). These 610 pavilions represent a subsection of the real number.

Towers assume a certain proportion like one of: (a), (b), (c), (d), (f), (g) or (h) in Figure 190. Essentially the left top corner of Figure 190.

(2) The pavilion with towers all around.

This will be spacingPlanarGapPartial or spacingPlanarGapMatching in our classification.

(3) The pavilion with many towers all around.

"Many" is a quantifier and we assume a quantity higher then ... three. From a pedestrian point of view we can not see all twelve towers at once. "Many" will correspond to cardApproximatly13OrMore in our cardinality classification set.

(4) The pavilion with many special looking towers all around.

We communicate that the towers are not cuboids. They look different.

(5) The pavilion with many special looking compact towers all around.

The towers are not thin and tall. Here we see the that natural language has a flexible but fuzzy way to carry the same information as the complicated named proportionZero-ZeroP1 (h), which has an easier to understand sketch in Figure 190. The adjective *compact* rules out (a), (b), (c), (f). In a spoken sentence a human would most likely not disambiguate between (d), (g) and (h) until it is really necessary.

(6) The pavilion with many special looking compact towers all around, that all look slightly different.

This is information about Variety like varietySome. It will also help to prefer spacing-PlanarGapPartial over spacingPlanarGapMatching.

(7) The pavilion with many noisy, stretched and sheared compact towers all around, that all look slightly different.

We start to describe the "special looking". When we inspect the Periphrase we see that many slots are candidates what to chose from next.[174] The decision here is one made with implicit statistical background knowledge by the single author. Lattice slots are seldom. The combination of three Lattice slots is very seldom. We discuss a theoretical statistical module in chapter 9.8.

(8) The pavilion with many towers all around, that all look slightly different. A typical compact tower is noisy, stretched and sheared and is tapering and tilting.

174 "next" because we have information about proportions. The information that the Lattice slot is more important than other slots could be document in the "boring Periphrase Syntax Tree" notation that we see in Figure 225 in chapter 8.4.

We have restructured the sentence into two to make it easier to read. Still the word "typical" also communicates some self-similarity. We provide information about tilt to communicate that tilt is present and a straight verticality is absent.

(9) The pavilion with many towers all around, that all look slightly different. A typical compact tower is noisy, stretched and sheared and is tapering and tilting and there is irregular faceted texture.

This corresponds to textureFacetedIrregular.

(10) The pavilion with many towers all around, that all look slightly different. A typical compact tower is noisy, stretched and sheared and is tapering and tilting and there is irregular faceted texture. There are non-perpendicular angles and obtuse angles.

Information about the View and Plane angles in the Periphrase like anglePerpendicular-OffMinor, angleObtuse.

(11) The pavilion with many towers all around, that all look slightly different. A typical compact tower is noisy, stretched and sheared and is tapering and tilting and there is irregular faceted texture. There are non-perpendicular angles and obtuse angles in a typical tower. The towers surround an exhibition hall.

We add information about the exhibition hall. A hall already carries implicit proportion information. Essentially the lower right corner of Figure 190 (r), (s), (t), (v), (w), (x), (y). We will use proportionZeroZeroM2 (w). We can narrow down on (w) because there are no qualifiers that indicate that the hall is stretched (t) (y) nor that it is compact (r), (s), (v). Again, in a spoken sentence a human would most likely not disambiguate between (s), (v), (w) and maybe (x) until it is really necessary. We discussed in chapter 8.1.1 that the proposed system is missing a concept for *surrounds*.

(12) The pavilion with many towers all around, that all look slightly different but are approximately the same size. A typical compact tower is noisy, stretched and sheared and is tapering and tilting and there is irregular faceted texture. There are non-perpendicular angles and obtuse angles in a typical tower. The towers surround an exhibition hall.

We introduce information about the Relative Size and Size Randomness of the sizes of the towers. We add this information for the towers before we talk about Relative Size of the exhibition hall. The semantic meaning of "hall" already carry implicit information. Halls are by default large.

(13) The pavilion with many towers all around, that all look slightly different but are approximately the same size. A typical compact tower is noisy,

stretched and sheared and is tapering and tilting and there is irregular faceted texture. There are non-perpendicular angles and obtuse angles in a typical tower. The towers surround a larger exhibition hall.

This is the explicit relative size information for the exhibition hall. Even though the exhibition hall is larger then a typical tower it does not qualify the exhibition hall to be more significant to the building shape identity of the pavilion. In natural language this is also expressed by the position of the blue sentence at the end of the paragraph, after the green and black sentences.

(14) The pavilion with many towers all around, that all look slightly different but are approximately the same size. A typical compact tower is noisy, stretched and sheared and is tapering and tilting and there is irregular faceted texture. There are non-perpendicular angles and obtuse angles in a typical tower. The towers surround a larger exhibition hall and are connected to it.

Information about Spacing arrangement spacingContactPartial. The sizeLarger is added in the sentence before the Spacing information spacingContactPartial, even though it is further down the branch in the Syntax Tree. This can be argued two ways. The item spacingContactPartial is actually the same as the default item, though it was added here explicitly to document that the Spacing was discovered. A different argument is that this is a flaw in the classification data by the single author.[175]

We now have a paragraph (14) that goes into some details to describe the building shape. We can observe many concatenations with “and”. The enumeration of the Periphrase of a typical tower also seems tedious and redundant. A human would most likely only add some of the Periphrase slots as their information overlaps.

Statement (14) is important, as it carries a lot of valuable information. We will later see that this redundant information will enable us to do a comparison with other pavilions based on a simple “strong independence” idiom (see chapter 9.2). But natural language can be more compact. Lets try to reduce statement (14), to be closer to what a human would more likely say.[176]

(15) The pavilion with many towers all around, that all look slightly different but are approximately the same size. A typical compact tower is noisy, stretched and ~~sheared and is tapering and tilting and there is irregular~~

175 It happened because it is easer to handle similar looking branches during reviews. As the current software information does not distinguish between merging point without a significance attribute this flaw has no impact to comparison calculation (see chapter 9).

176 We have ten Periphrase slots in our classification system. They contain some overlap. We will experiment in chapter 12.3 which of the Periphrases contribute the most when compared to empirical data. Such an empirical test could also serve as the decision which of the additions in statements (6), (7), (8), (9) or (10) should be dropped.

~~faceted texture.~~ There are non-perpendicular angles ~~and obtuse angles in a typical tower~~. The towers surround a larger exhibition hall and are connected to it.

When we compete with natural language we are in a disadvantage position because natural language can reach out to cognitive semantics to implicitly enrich the information. We might further reduce the sentence by using some natural language semantic inferences.

- "slightly different" already carries similar information to "~~but are approximately the same size~~".
- "~~larger~~" is already encoded in "hall".
- "~~are connected to it~~" is the default behaviour, as a *typical* pavilion is *one* building.
- We do not need to distinguish between the two self-similarity Periphrases in natural language and skip the "~~a typical compact tower~~" and just talk about "the compact towers".
- In the introduction sentence to the exhibition hall, we now do not need to repeat "~~The towers~~" but reduce it to "They", as they are the subject of the previous sentence.

Therefore we can further reduce:

(16) The pavilion with many towers all around, that all look slightly different ~~but are approximately the same size.~~ ~~A typical~~ compact tower is noisy, stretched and there are non-perpendicular angles. ~~The towers~~ surround a ~~larger~~ exhibition hall ~~and are connected to it~~.

So a compact natural language sentence might be:

(17) The pavilion with many towers all around, that all look slightly different. The compact towers are noisy, stretched and there are non-perpendicular angles. They surround an exhibition hall.

A pavilion without a space for an exhibition on a World Exposition site is very uncommon. Therefore we might skip the exhibition hall as well. The human mind might also go way further and use a metaphor.

(18) The pavilion with the dancing towers.

Metaphors are powerful but can be a slippery slope when our conversation partner misinterpret them.[177] We might even argue to skip "the pavilion", because on a World Exposition site a pavilion is the default building type. We see that the context matters

177 *Diamondmushroom.*

and natural language can utilize common ground and prior knowledge. But the sentence "Let's meet at the dancing towers" might a bit to vague.

Unfortunately we do not have cognitive semantics and the capability for metaphors in our small proposed building shape classification system at hand.

We now return to statement (14) and try to expose the classification sets form chapter 7.3 (Periphrase) and 8.2 (Syntax Tree). We will single out the words in parenthesis and annotate them with superscript.

(19) The pavilion with (many)[cardinality] (tower)[periphrase](s)[self-similarity] (all around)[spacing], that (all look slightly different)[variety] but are (approximately the same size)[relative size & randomness.] A typical (compact)[proportions] (tower)[periphrase] is (noisy, stretched and sheared)[lattice] and is (tapering and tilting)[tilt] and there is (irregular faceted texture)[texture]. There are (non-perpendicular angles and obtuse angles)[plane and view angles] in (a typical tower)[periphrase]. The (tower)[periphrase]s (surround)["orientation"] a (larger)[relative size] (exhibition hall)[periphrase & proportions] and are (connected to it)[spacing].

Lets get an *impression* what a software "sees" when it substitutes the natural language with technical names. We remove the fluent natural language parts in the parentheses with the technical names.

(20) The pavilion with (*cardApproximatly13OrMore*)[cardinality] (periphraseOne)[periphrase](copyOfPeriphraseOne)[self-similarity] (*spacingPlanarGapPartial*)[spacing], that (*varietySome*)[variety] but are (*sizeApproximatelySame*)[relative size] (*randomMinor*) [randomness.] A typical (*proportionZeroZeroP1*)[proportions] (periphraseOne) is (*latticeNoise*, *latticeStrechUnproportional* , *latticeShear*)[lattice] and is (*tiltTaperMinor*, *tiltWidenMinor*)[tilt] and there is (*textureFacetedIrregular*)[texture]. There are (*anglePerpendicularOff*, *anglePerpendicularOffMinor*, *angleObtuse*)[plane and view angles] in (periphraseOne)[periphrase]. The (periphraseOne)[periphrase]s (*orientationInside*)["orientation"] a (*sizeLarger*)[relative size] (periphraseTwo)[periphrase] (*proportionZeroZeroM2*) [proportions] and are (*spacingContactPartial*)[spacing].

We can now transform statement (20) into a hierarchical bullet list. This erases the remaining natural language fragments like "and there is". We will first define a group of rules for the bullet list in statement (21). The rules are:

- At the first level the bullets denote Periphrases.
- Vertical order carries information about significance.
- The enumeration within a bullet with a colon allows more then one item per bullet.

- Use of bold type font to mark up significant items.
- Indentation, as a two dimensional feature, allows to distinguish between Periphrase and Syntax. We will use a square bullet to mark up the Periphrase slots.
- Indentation also allows the creation of subbranches where one classification item annotates a different one inside a Syntax Tree.

When we apply above rules we arrive at:

(21) (the bullet list below)

- PeriphraseOne
    - ■ (***proportionZeroZeroP1***)proportions
    - ■ (***tiltTaperMinor***, *tiltWidenMinor*)tilt
    - ■ (*latticeNoise*, *latticeStrechUnproportional* , *latticeShear*)lattice
    - ■ (*textureFacetedIrregular*)texture
    - ■ (*anglePerpendicularOff*) plane angle
    - ■ (*anglePerpendicularOffMinor*, *angleObtuse*)view angle
- CopyOfPeriphraseOneself-similarity (same Periphrase slots omitted for brevity)
    - (***spacingPlanarGapPartial***)spacing
        - (***cardApproximatly13OrMore***)cardinality
    - (***varietySome***)variety
    - (*sizeApproximatelySame*)relative
        - (*randomMinor*) randomness
- PeriphraseTwo
    - ■ (*proportionZeroZeroM2*) proportions
    - (*sizeLarger*)relative size
    - (*spacingContactPartial*)spacing
        - (*orientationInside*)"orientation" (theoretical value, not part of the official orientation classification set)

This is the explicit list. The software sees also the default classification items which are left out of above bullet list. These are visualized as grey faded out sketches in Figure 216 (three items) and in the two Periphrase Figures 220 and 221.

PeriphraseOne (tower) has four additional default items: (*edgeSharp*)plane edge, (*edgeSharp*)view edge, (*curvaturePlanar*)curvature, (*featureNoSignificant*)feature.

PeriphraseTwo (exhibition hall) has even nine out of ten additional default items: (*anglePerpendicularStrict*)plane angle, (*edgeSharp*)plane edge, (*anglePerpendicularStrict*)view angle, (*edgeSharp*)view edge, (*tiltApproximatelyNone*)tilt, (*textureSmooth*)texture, (*curvaturePlanar*)curvature, (*featureNoSignificant*)feature, (*latticeNoSignificant*)lattice.

When we would add the default items to our structured bullet list (21) it would more then double the count of bullets.

Above bullet list with its rules and conventions[178] is already similar to a Syntax Tree. Though the visual binary tree diagram is able to introduce some visual consistency and tranquillity. Imagine we have to compare two bullets list of two different buildings. We put them side by side. To correlate items on both sides a lot of manual reading and rereading of the bullet lists must be done. The Syntax Tree together with Periphrases has a certain visual consistency. Related information is most often at consistent spots. For instance the Periphrase has a fixed sequence of classification slots. When we have two Periphrases then they merged into the most left and most right Syntax Tree leaf.

When we would inspect the XML file for the Russia pavilion[179], which is the base for the generated visualisations like in Figures 216, 220 and 221, we would see some vague similarities to the bullet lists. The software implementation digests data in the form of structured hierarchical mark-up text.

This visual consistency in contrast to the bullet list, is a quality of the proposed system which is aimed at human viewers rather then machines.

178 In applied software engineering this is leading towards a Domain Specific Language (DSL) or at least a data Schema. One could write a software parser for it. But we have just examined a single pavilion. To make this DSL/Schema reusable we would need to do a procedure similar to the one done for Syntax Tree and Periphrase in this thesis. If this DSL/Schema is better usable is a research question for its own.
It depends on the context of the 80 buildings.

179 The Russia pavilion is just one example. All visualisations in Appendix A (19.1) are based on XML files with similar structure and common rules. See Appendix E (19.5) for a technical example.

8.4. The Theoretical Symmetry Phrase

This chapter explains two related extensions of the core concepts that we have encountered so far. The extensions are theoretical and not implemented in the software used in this thesis. They show a potential and the repeating occurrence of two ideas that we have encountered in the interdisciplinary chapter 5: Recursion and Symmetry.

This subchapter shows a richer overall system but is located as a subchapter in the Syntax Tree chapter. It generalizes the use of binary trees not only in the composition layer but also in the Periphrase layer as well as additional deeper layers. These new binary trees all follow very similar rules to the Syntax Tree for the composition layer. We discuss this before chapter 9 which is about comparing two building shapes. The *comparing* part is constraint to "what is implemented" in the software. This subchapter should be a good place to describe theoretical enhancements[180] before the thesis gets more applied and later adds empirical reference data.

We will gain from insights of the linguists Ray Jackendoff and the Visual Perception researcher Zygmunt Pizlo. We will take two concepts that distinguishes them from their peers in their research domains and see if a transition of technique is possible to building shape classification.

The concepts are:

- Jackendoff's (see chapter 5.1.2) openness to allow linguistic generative capacities not only in syntax, but also in the lexicon[181] and semantics. Binary/n-ary trees appear at more places than in mainstream linguistics theories.
- Pizlo's (see chapter 5.3.4) emphasis on symmetry as the most important cue for recognizing shapes.
- A combination of both: Representing symmetry information as small binary trees and allow these subtrees to be added at multiple places throughout the system. We will call these subtrees *Symmetry Phrases*[182].

180 Chapter 9.8 also describes a theoretical enhancement called the "Statistical Module".

181 Most language theories have a component called the *lexicon*. It is the place in the human mind of long term memory for words and morphemes. Linguistics uses *lexicon;* Mitchell and Shiny use *vocabulary.*

182 Terms like *phrase* must be used carefully, because each term defined in one domain reused in another one is dangerous as it caries the burden of its meaning in the origin domain. We did a similar transfer with the word *Periphrase*. Alternative names could be less meaningful like symmetry subtree, or symmetry fragment, because they do not contain the notion that we will perform recursive operations on them.

Lexicon - Kick the Bucket

One of Jackendoff's (see chapter 5.1.2) examples for a smarter lexicon is the phrase "kick the bucket"[183] as an idiom for "die". The phrase itself has a simple syntax but it is still stored in the lexicon, rather then being generated by the main syntax facility every time. Therefore in his theory the lexicon must be able to store not only words but binary/n-ary trees as well. Jackendoff sees this as an explicit improvement compared with the mainstream view in his domain. Mainstream researchers treat the lexicon as a simpler less smart entity and the underlying principle of recursion is "reserved" for us in syntax. Jackendoff states that this is to limited and argues that recursion happens in other parts of the mind, like *Vision.* There is no need to restrict the generative capacity to only syntax. Jackendoff further generalizes this assumption and allows binary/n-ary trees in additional places like semantics[184]. He leaves the setup open and considers that it might be the primary data structure in many parts of the brain, for example in Visual Perception. It might be of interest for other cognitive sciences.

Pizlo

We will extract the enumeration of "Five Important Conceptual Contributions" from the final chapter from "Making a Machine That Sees Like Us" (Pizlo *et al.*, 2014, p. 205). This will partly overlap with insights from chapter 5.3.4, but we repeat it here because the central concepts of Periphrase and Syntax Tree are now introduced. We will reflect how they relate to Pizlo's approach in Vision. We will briefly go through Pizlo's first four statements and then continue with the important impact of statement (5).

(1) 3D Vision is an inverse problem

Pizlo credits Poggio et al[185] for bringing the *Theory of Inverse Problems* into Vision research. It allows to split the investigation of *sensation* and *perception* into two different task. While sensation can be considered as a *direct problem*, perception can be investigated as an *inverse problem*. Rather then following the pattern "this is the cause, what are the effects?" the inverse approach flips to "this is the effect, what are the causes". Inverse problem are often harder to tackle. Pizlo is connecting "the effect" to theories like Prägnanz and the Gestalt movement. The inverse problem approach discloses the complexity of the topic. One possible solution to the complexity can be human innate competence, similar to the Cognitive Revolution. This solution leads towards Pizlo's statement (2).

183 A German language counterpart would be: "Den Löffel abgeben".

184 The areas of *semantics*, *syntax*, *lexicon* and the *interface* that connects them are focus areas of Jackendoff's linguistic research contributions. Additionally he often incorporate *phonology* and *pragmatics* into his setups.

185 Poggio, T., Torre, V., & Koch, C. (1985). Computational vision and regularization theory. Nature, 317, 314–319.

This thesis is in the domain of Building classification. The *inverse problem* is not a fundamental pillar like with Pizlo, but rather an appearing pattern. It appears when we work with humans in the empirical part.

In the empirical part of this thesis the perception and comparison of World Exposition pavilions is at centre. It is considered the technical goal to be close to human behaviour. Rather then asking the participants to use the classification system and assign it to buildings, the data gathering focused on the softer inverse effect. The participants state the effect that two pavilions look similar in their building shape. It is the inverse technical task to find the cause, or at least hint towards a model that might explain it.

Pizlo states that "[...] and Bayesian inference are the right tools for modeling vision". We will settle on a related approach to Bayesian inference when we start compare building shapes in chapter 9

(2) Nature of a priori constraints (priors)

Pizlo points out that there are multiple a priori constraints :"such as the symmetry of the objects, their 3D compactness, the planarity of their contours, as well as the direction of gravity [...] and [...] the horizon". Pizlo will give symmetry a special place in statement (5).

This thesis also embraces a priori constraint, though in a more modest scope. The departure from a quantitative construction-focused approach and the move towards a qualitative perception approach is also supported by the role of gravity for humans as well as buildings. The perception of verticality is connected with gravity as well. This leads to classification sets like Tilt.[186]

(3) Veridicality as *the* central concept in vision.

While this is an important differentiator for Pizlo within his domain, it might be less controversial within building shape classification. *Primal access* within e.g. 100 milliseconds is not the main criteria for this classification. We assume that people have more time and thought about their surrounding environment. People are at a location to perform certain day to day tasks and therefore navigate through the space.

Pizlo strongly criticises the use of illusions in the empirical experiments of his peers. He claims that the experiments perform so odd because this is not what our mind assumes to see. Illusions are seldom in nature and our mind applies the a priori constraints like the law of Prägnanz to see the "obvious". While illusions are a design tool in the repertoire of an architect to achieve a certain effect for the users of the buildings, they are the exception[187]. This thesis makes the deliberate choice to not strip away the context

186 The perception approach is also supported by a speculation that humans might have an innate concept of "shelter from the environment", which we might call "building" as well. looking at a man made structure of a certain size and proportion we might instantly apply defaults which accelerate following inferences.

187 Though World Exposition pavilions are a type of building that use this tool. One example is the United Kingdom Pavilion in Shanghai 2010 with its use of tubes to blur the definition of its shape. A similar effect

of buildings presented to participants in the empirical part. Horizon lines, walking pedestrians, street lamps, shadows and neighbouring buildings are all included in most of the photographs.[188] There is no test for "Is this a building?"

(4) Computational and robotic modeling is the only good way to formulate theories in vision from here on.

Being in the fortunate position that the author of this thesis can also do software development and provide a partial implementation of the theoretical model, it is possible to comply with Pizlo's statement.

(5) Our new analytical definition of shape is based on an object's symmetries.

We have discussed in chapter 1.2 that Pizlo's analytical definition of shape refers to its self-similarity rather then to similarity between different objects. We follow a different definition that allows for comparison between different building shapes. Still we see that Pizlo singles out *symmetry* and gives it an distinct position in the system. Pizlo argues that we have an innate capability to recognize symmetry with little computation effort. Supporting visualisation like Figures 222 and 223 allows the reader to follow the argument.

Due to Pizlo's different definition of shape we can not transfer his approach to the one discussed in this thesis. Still "extracted by specifying the object's symmetries" can be an inspiration, especially when we take the plural form of "symmetries" into account.

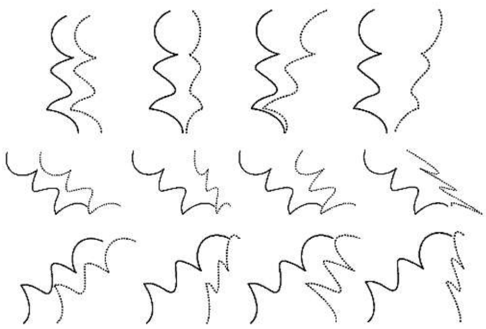


Figure 222: Illustration 4.10 from (Pizlo *et al.*, 2014, p. 140) -- Twelve pairs of 2D curves. These represent all possible types of 2D transformations that conform to 3D symmetry and planarity constraints

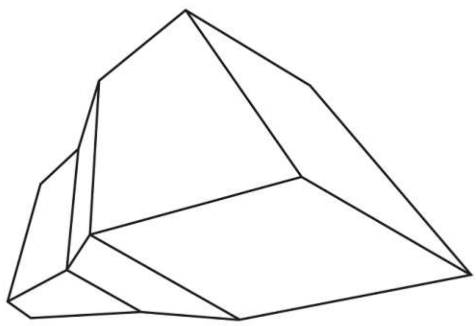


Figure 223: Illustration 4.2 from (Pizlo, 2008, p. 122) -- Illustration of a monocular perspective cue. This is an image of a mirror-symmetrical object. The image itself is not symmetrical. Its symmetry is distorted.

Symmetry Phrase

What can we gain from these two inputs from Jackendoff and Pizlo for building shape classification? A combination of both ideas might be transferred: Representing sym-

is used in the Caltex pavilion in Yeosu 2013. The Poland pavilion in Milan 2015 uses mirrors in its top garden roof to give the illusion of a wider green space.

188 Only real completed buildings are used. No "architecture competition renderings" or technical drawings are used. There is a single exceptions to this: B6 - Expo 1958 Fleche Du Genie Civil (Bruxelles) has one museum model photograph to help decipher the old low quality original photographs.

metry information as small binary trees and allow these subtrees to be added at multiple places throughout the system. We will call these *Symmetry Phrases.*

Boring Periphrase Syntax Trees

As an intermediate step towards Symmetry Phrases we need to discuss one nature of the Periphrase. The Periphrase was introduced in chapter 7 as an innovation, with a simple representation of (at least) ten classification items in a row of ten slots like in Figure 224. But a Periphrase could also be represented as binary tree as visualized and described in Figure 225. The result would be a "boring Periphrase Syntax Tree" where the branches and joins hardly carry any additional information compared to the representation as a row. Though the concepts remain and blend: the place where the branches merge into the main axis carry the significance information. The same *rule of dominance* and *rule of significance* would kick in[189]. Minor and inferred classification items would merge further down; normal and significant items further up the main axis. Therefore one disadvantage would be, that the sequence of the row of leafs would not be stable and harder to read and compare. A second disadvantage would be the more verbose two dimensional representation.

189 We will discuss these *rules* later in chapter 9.7.3. As a software implementation detail: The software reuses the same rule source code at all places. This is possible because the rules are quite simple. They are a function that take an input numeric value, plus some simple context information and produces and output numeric value.

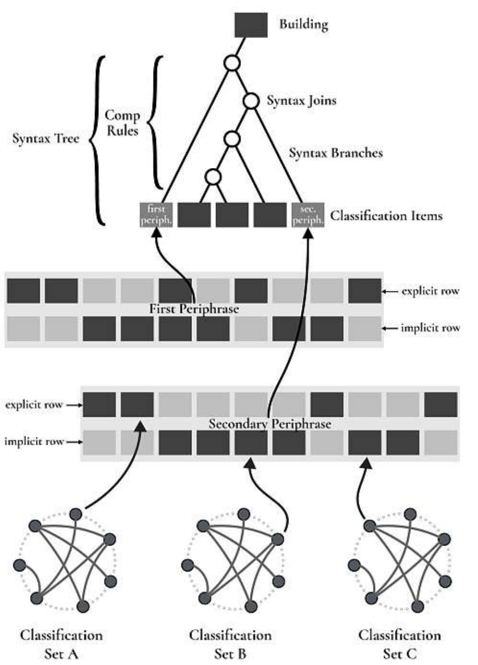


Figure 224: Overview of the concepts introduced in this thesis. See Figure 60 for a bigger version of this diagram

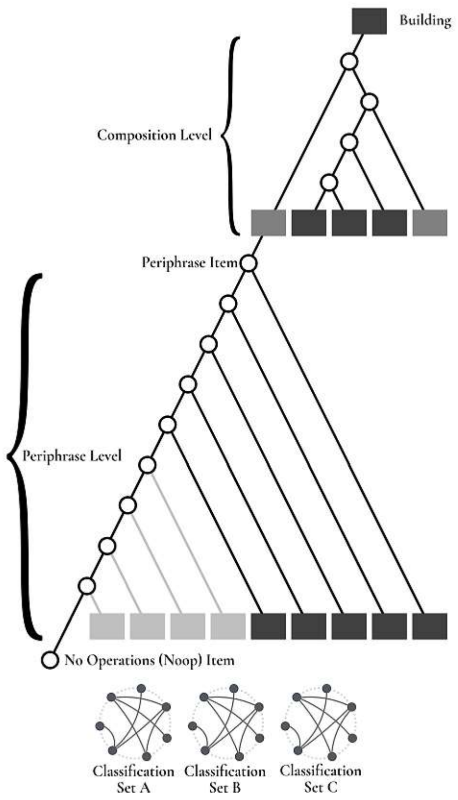


Figure 225: Alternative representation of the Periphrase. Instead of displaying it as an explicit plus implicit row we can represent the information as a "boring Periphrase Syntax Tree". All items merge directly into the main axis. Explicit items (darker grey) merge further up into the main axis. Implicit items (lighter grey) further down.

When we understand that a Periphrase is just a "boring syntax tree", what is left there that makes it special? The *Circumlocution* nature of the Periphrase drives the selection of the classification sets that are used. We should also not forget the "Common Ground" argument discussed in chapter 7.2. A Periphrase will *always* contain ten slots. Slots without an explicitly assigned classification item will snap to a default that describes the *perfect cube*. The *perfect cube* assumption allows the explicit assigned classification information to concentrate on the *identity* of the distinct building part, rather then repeating the same information over and over again, in an error prone way. This predictable behaviour makes working with, and reasoning about Periphrases easier.

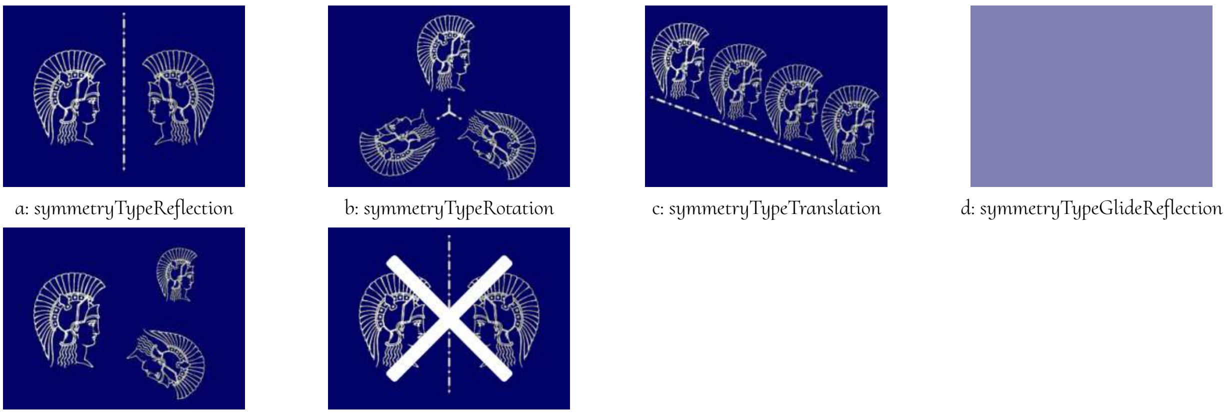
The term symmetry is commonly used as a synonym for two dimensional *reflection symmetry*[190]. There are additional classical two dimensional types like *translation symmetry* and *rotation symmetry*. The forth classical type is *glide reflection symmetry* but it is less common in building shape. *Scale symmetry* and *dilatational symmetry* are also candidates, but can be covered by the *Lattice* classification set in the Periphrase.

190 Also known as *mirror symmetry*. We stick with *reflection symmetry*, because this is the term that is used by most geometrical definitions.

Three dimensional space has additional types like *helical symmetry*[191] which we will omit. We will omit complex three dimensional symmetry types because we use our symmetry classification set to augment classification items at the *leaf level* or within abstract classification sets themself. For the Periphrase these leafs are a fixed set of ten slots with the following dimensional constraints:

- Angle-Plane, Edge-Plane, Tilt-View, Angle-View, Edge-View. These are bound to a two dimensional plane of orientation.
- Texture is bound to a surface, and “happens” on this local two dimensional surface.
- Surface and Feature are three dimensional. They *might* benefit from more complex symmetry, but this is not evident in the small set of 80 World Exposition pavilions which is used in this research.
- Lattice and Proportions work on a *bounding box*, which is three dimensional. But the bounding box is predefined in its symmetry to the properties of a box.

A potential *symmetry type classification set* might look like in Figure 226. Please note that it also contains two additional members: symmetryTypeNoSignificant *(e)*, because symmetry might not be obvious or less important and a strong symmetryTypeAvoided *(f)* because the designer might explicitly try to avoid symmetry, to challenge the expectations of the users of the pavilion.



a: symmetryTypeReflection b: symmetryTypeRotation c: symmetryTypeTranslation d: symmetryTypeGlideReflection e: symmetryTypeNoSignificant f: symmetryTypeAvoided

Figure 226: Potential Classification set: Symmetry Types (all items)

When we engage to symmetry as something more then just reflection symmetry, we can discover it at many levels:

- (1) At composition level a pavilion might have a symmetrical setup. Maybe it consist of three distinct building parts in a row or a circular arrangement.
- (2) At Periphrase root level one distinct building part might have a strong symmetry as a whole.

191 We have a curated group that is related to helical symmetry which contains spiral like buildings, but it was decided to move this into the feature classification set. This is also due to the fact that spirals in architecture are a combination of helical symmetry and scale transformation, or scale symmetry.

- (3) At Periphrase leaf level one classification item in a slot might be more precise when augmented with symmetry information.
- (4) Inside a *classification set* symmetry information might help to distinguish different members of the same set.

We will pursue (1), (3) and (4) but we will drop (2). While it looks logical and tempting to have symmetry information applied on the whole Periphrase, it is also risky. It looks logical from a 3D construction and geometrical point of view because we can envision clean symmetrical building shapes. There are at least three arguments against:

- Architecture is not as clean. In theory a single small feature like a door that has not a perfect symmetrical counterpart, maybe due to site restrictions or street access, would be a reason to question the symmetry information.
- We would weaken the *Circumlocution* nature of the Periphrase, because we would treat it as an entity similar to the 3D construction workflow.
- The implementation is difficult. If we add symmetry type as the eleventh slot, where do we put the symmetry axis information? As the twelfth slot or as a subtree of symmetry type? We lose the connection between both in the first case and we lose the uniformity of the Periphrase in the second case. As an alternative we could add symmetry at a separate level tucked in between composition level and Periphrase level[192]. In such a setup we would promote symmetry and make it more important then the other ten slots.

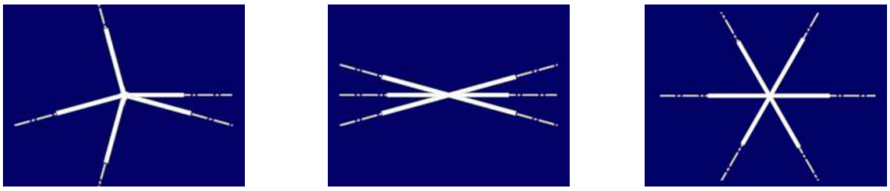
Of course symmetry can appear at the Periphrase level but we can compensate for the decision to drop (2) by allowing symmetry at the leafs of Periphrases (3).

Above enumeration already hints that symmetry comes in many shades. The complexity and ambiguity of symmetry classification might be eased by breaking it up into smaller pieces. The potential candidates are:

- Symmetry types – see Figure 226
- Symmetry axes distribution – see Figure 227
- Cardinality of symmetry axes – see chapter 8.2.2.
- “Degree of Straightness” – Omitted – Different to the common conception of straight axes in geometry, the idea of an axis in architecture or organic nature is not as strict. In practise an axis could be bend or be an arc. More generally speaking, it could be any kind of curve. In nature, the centre of the stem of a flower which is

192 From a software implementation point of view this would not be as challenging. It reassemble the “old concept” as visualized in Figure 233. At worse it would add “yet another level” but due to *recursion* the complexity would not spike.

bend by wind or gravity is still considered to be axis of symmetry. We could in theory extract a small classification set, but will omit it. This kind of information can be partially transported by the Lattice classification set with its items like latticeBend, or latticeTwist.



a: symmetryAxesDistributionUneven b: symmetryAxesDistributionRhythm c: symmetryAxesDistributionEven

Figure 227: Potential Classification set: Symmetry Axes Distribution (all items)

To connect the pieces we can again use the existing data structure of the binary trees with the same rules. Therefore we would benefit from *recursion* and there would be no need to add new patterns.

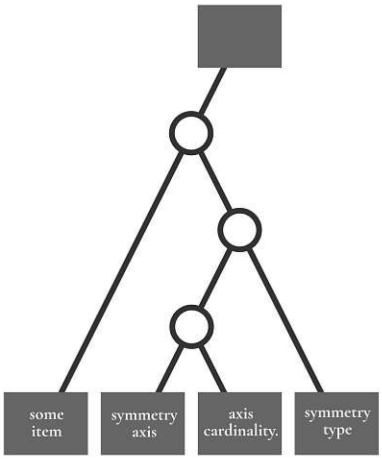


Figure 228: classification items that participate
in a symmetry phrase to augment “some item”.

Lets examine two simple Symmetry Phrases at the Periphrase leaf level. The first example is the default perfect cube, the second if the cylinder from our canonical example the Kaleidoscope.

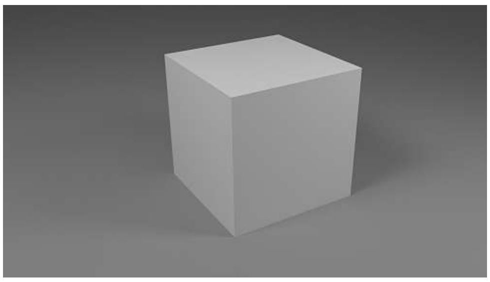


Figure 229: the perfect cube

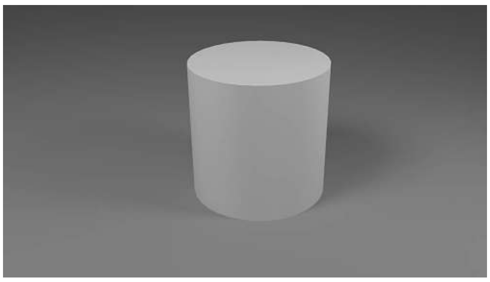


Figure 230: a cylinder like in the Kaleidoscope

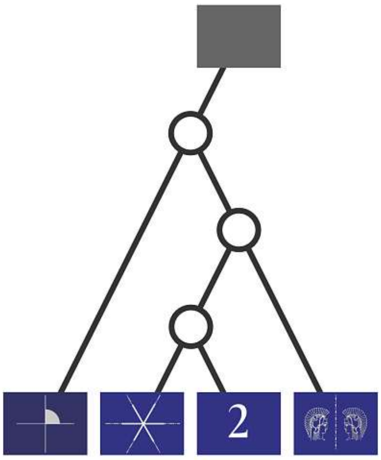


Figure 231: Perfect Cube: potential symmetry phrase that augments the Plane-Angle slot which is occupied by anglePerpendicularStrict (most left item)

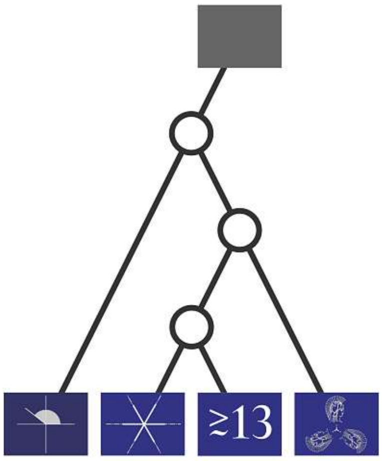


Figure 232: Cylinder: potential symmetry phrase that augments the Plane-Angle slot which is occupied by angleObtuse (most left item)

We augment the Angle-Plane Periphrase slot with symmetry information:

- The *perfect cube* in Figure 229 and Figure 231 defaults to anglePerpendicularStrict for the Plane-Angle slot. We would augmented with symmetryTypeReflection[193] and symmetryAxesDistributionEven[194], with an axes Cardinality of card2[195].
- The cylinder in Figure 230 and Figure 232 has an explicit angleObtuse and would be augmented with a symmetryTypeRotation and symmetryTypeReflection, with an axes Cardinality of cardApproximatly13OrMore, which is the closest to describe “infinity” in our Cardinality classification set.

The Symmetry Phrase for the perfect cube is the *default* Symmetry Phrase for the Angle-Plane slot. So there is no need for a human to even add it. It will be provided implicitly as a fallback by the software if any explicit information is missing. This behaviour is the same as in the composition level Syntax Tree.

193 An alternative might be to assign symmetryTypeRotation instead. This is possible for a perfect cube, but not for a more general stretched box. As most people would rather see this family resemblance between cube and box we opt for symmetryTypeReflection.

194 We use the *Symmetry Axes Distribution* classification set from Figure 227. We could argue that there is no information that the symmetry axes are at 90 degree. We might request to have yet another branching to describe the angle between the axis. We could describe the angle with the existing *Angle* classification set. While theoretical correct, we avoid it and rely on simple inference: When the axes would be at a different angle then we would describe a rhomb and that would contradict the information which the whole branch augments. We must also judge how much value yet another branch in the symmetry phrase would deliver. Especially when the information might be redundant or even potentially contradicting.

195 It might be tempting to allow a separate Cardinality item right into the Plane-Angle slot to emphasise the fact that there are exactly *four* 90 degree angles. But please remember that the current cardinality classification set does not even contain a “4” but rather Fibonacci numbers 1,2,3,5,8,13. Though we might again argue that this information can be inferred from the other values. If we have two perpendicular symmetry axes, reflection symmetry and anglePerpendicularStrict, the only possible Cardinality of the angles is 4. Similar arguments work for a hexagon or octagon. Though again, the hexagon is missing the “6” in the Cardinality classification set.

We can already see by the extensive footnotes for the *perfect cube* that symmetry carries a hidden complexity. But lets not forget that we just augmented a single Periphrase slot. By adding additional – possibly identical – Symmetry Phrases to other slots we can emphasise the symmetry. For instance for a cylinder we might add the identical Symmetry Phrase to the curvatureConvexStraight. On the other hand we might add very different Symmetry Phrases to a slots like Texture or Lattice.[196]

The Symmetry Phrase on the composition level would follow the same approach as the just discussed one at the Periphrase leaf level. Symmetry Phrases on *classification items* inside a *classification set* work technically the same but their goal is to provide identity to one member of the classification set. In other words: to make it distinguishable from its peers. Therefore the Symmetry Phrase here must be balanced against the other required in the peers. For instance the Spacing classification set might be a candidate for additional symmetry phrases. Or on the other hand could be simplified to just a few items and the additional information is transferred into the Symmetry Phrase.

We arrive at a theoretical setup as depicted in Figure 234. The rest of this chapter will discuss implication of the extension for the software implementation and some comparison with earlier iterations.

196 Picture the Beijing 2008 Olympics “Bird’s Nest” stadium. It might get a symmetryTypeRotation on the angleObtuse, but get an significant symmetryTypeAvoided on Texture and a symmetryTypeReflection on the latticeStrechUnproportional.

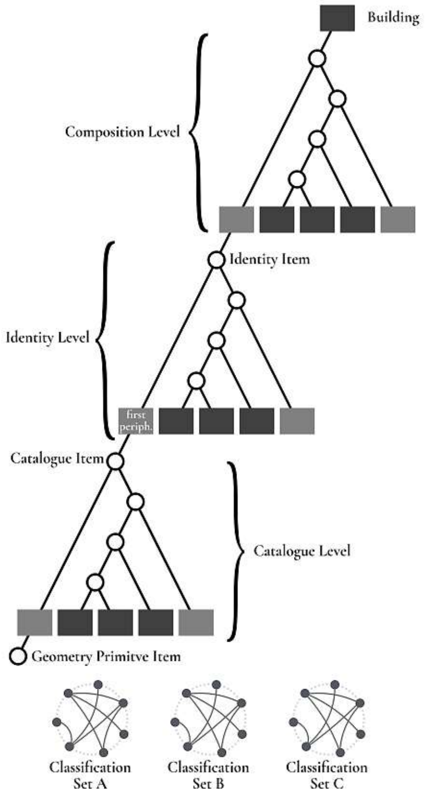


Figure 233: The "old concepts" from early stages of this thesis. With a composition, identity and catalogue level. Before the adoption discussed in chapter 4.2 and 6.5.1.

Please note the technical similarity to Figure 234. There are multiple "Levels" with Syntax Trees which are reduced to a single value before they enter the next higher level at an interface.

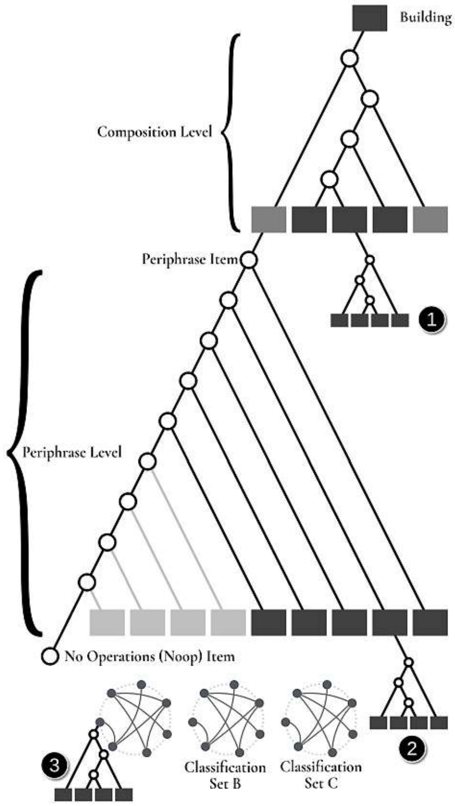


Figure 234: Extension of Figure 225. We add three example "Symmetry Trees" at various places.
Please note the "technical similarity" explained in Figure 233.

(1) A Symmetry Tree that augments a classification item from the Composition Level / Syntax Tree Level

(2) A Symmetry Tree that augments a classification item from the Periphrase Level

(3) A Symmetry Tree that augments a classification item inside a classification set. This is similar to Jackendoff's "kick the bucket" phrase in the linguistic lexicon inside a human mind.

We will see in chapter 9.2 that we will use a *strong independence* approach similar to a *Naive Bayesian* classification system. Because instances of Symmetry Phrase appear multiple times in one tree like in Figure 234, it would potentially require to convert the system into a *context aware* one. This might be necessary to avoid ambiguities and false positives. Though by displaying a Periphrase as a boring syntax tree, we can see a different solution, that is also supported by some abstractions that date back to earlier stages of this thesis.

Figure 233 displays the *old concept*. Three levels are present: composition, identity and catalogue. The data structures in all levels are similar. We can identify *recursion* at a higher level. Between each pair of levels, an interface operation collapses the deeper information into a single entity. Major parts of the software implementation are supporting this approach. The Periphrase – which arrived later – is treated specially, but it is collapsed to a single entity at the interface just like a *boring Periphrase syntax tree* would be. The software also support *three level deep* data structures. In theory this could be extended to *n-level deep* data structure.

The new Symmetry Phrase would behave in the same manner as the elements in the old concept. It would be collapsed into a single entity at an interface. Because this happens for every Symmetry Phrase the contradiction caused by multiple instances of classification items from the symmetry information would disappear. We can again follow the easier to implement *strong independence* approach.

In chapter 9 we will discuss how a default numeric value of 100 is assigned for a Periphrase slot. The Symmetry Phrase discussed in this chapter is theoretical and is not implemented in the software. Therefore we will just outline here its behaviour when used in comparison. When we have explicit symmetry information, then it should be acceptable to have values higher then 100. We assume that when we skip any symmetry information then a default Symmetry Phrase is used as a fallback. The fallback is exactly the symmetry phrase that we discussed for the *perfect cube*. The two general direction available:

- We can reduce the main value that is augmented by a Symmetry Phrase so that the whole structure for the *perfect cube* contributes exactly 100 like the other slots.
- We can allow slots with Symmetry Phrases to contribute more then 100. This makes them more valuable then other slots, but this might be acceptable because they do carry more information. Based on the *rule of significance* this will be only in the range of 23 points for the perfect cube.

We finish the subchapter about the *theoretical Symmetry Phrase* and return to parts that are implemented by the software; like the comparison of building shapes.

9. Comparing Building Shapes

9.1. Using Collections of Buildings

The focus of this research is how collections of buildings can be improved and consumed. Therefore we deal with more then one Building Shape.

In the previous chapters we introduced concepts that can be used to describe the building shape of a World Exposition pavilion. At this stage it would be possible to create a retrieval system that can return buildings shapes that match a technical query. This retrieval system could be used to find a building in a collection that we already knows about but lost track of. Lets assume we want to find the Kaleidoscope building from within a bigger collection. We might specify that we are looking for angleObtuse in Angle-Plane and edgeSmooth in Edge-Plane. If the result set is to large te could be asked to further specify our query parameter. We might refine the query to require a Curvature of curvatureConvexStraight. The software would filter out all building shapes that are missing these criteria. We can continue the refinement process and filter out more and more building shapes that are missing the classification item from the filter statement. At a certain point we have reduced the result set to a size that is manageable, and identify the Kaleidoscope. There is also a chance that we miss the Kaleidoscope because we might have specified a query that includes a classification item that the Kaleidoscope does not have assigned.

The technology that is traditionally used to achieve above behaviour is *relational database technology*. There are associated tools like the Structured Query Language (SQL) that help in the process. With this approach there is only a binary in-or-out decision for membership in the result set. The behaviour is useful in many situations and it is a vital part of many commercial and academic products that work with data.

Another retrieval system which we got accustomed with as users are commercial and open source *search engines*. Because search engines are of commercial value they utilize a lot of technology at once, to stay ahead of competition. They can use a knowledge graphs to infer smart synonyms, push results based on machine learning algorithms, and use a distributed system to handle large volumes of data. Matches in a result set do not require to contain all query parameters. From an end user point of view search engines mainly return a ranked list with the best matching result listed first.

Recommendations results are similar to search engine results From and end user point of view. They differ in the way they start. In a digital setup we might focus on a particular object with detailed information on a screen. This can be a product page on an online shopping web site or a page focused on one architecture building with a particular building shape. A recommendation is a list that could state "you might also be interested in this product" or "buildings with a similar building shape". A good recommendation list is ordered similar to search engine results with the most relevant result at the top. Recommendations make *exploratory browsing* more user friendly. Exploratory browsing is hard to achieve with only search engine queries or database filtering at hand. Though methods like *faceted browsing* can improve the user experience in these situations.[197]

Ideally an end user can use all three: filtering, search queries and recommendations to achieve a goal. This chapter will focus on *similarity*[198] and the *ranking* of similarity. Of the three patterns, similarity is most related with recommendations. From an application point of view, the calculation of similarity could be foundation work for an exploratory browsing module in a future building shape web application.[199] From a theoretical point of view, this will allow us to compare the results from this calculations with empirical data gathered for this thesis in chapter 11.

9.2. Simple Similarity

The calculation of *similarity* which will be introduced in this thesis does not include advanced statistics nor *machine learning*[200]. It will use a simple scoring model and some tree traversal in the Syntax Tree part, accompanied by a group of simple rules. The complexity is approximately at a similar level as a Naive Bayes Classifier. We will assume "strong independence" of different matches, and sum up the independent results into one final score. Even though simple in its base assumptions Naive Bayes systems have proven to perform well for many tasks. They were often the first choice when a new field was explored[201]. They are usually outperformed by context aware systems, though often

197 *Faceted Browsing* is a way to navigate collections that are attributed with a lot of small classification sets also called *facets*. The classification sets introduced in earlier chapters could serve as facets as they are all flat and limited in size.

198 Using a shape abstraction as the base for a similarity calculation is also something that the Vision researcher Biederman sees as a valid path. It might be possible with his idea of Geons (see chapter 5.3.2). "A similarity measure reflecting common and distinctive components (Tversky, 1977) may be adequate for describing the similarity among a pair of objects or between a given instance and its stored or expected representation, whatever their basic or subordinate-level designation." (Biederman, 1987, p. 143) Biederman (1987, pp. 142, 143) discusses similarity, the implications of components and their relationships for similarity. Biederman's components might be reflected in Building Shape Periphrases and Biederman's composition in Building Shape Syntax Tree.

199 When the main task of this thesis would be to create such a web application there would be a bigger focus of utilising existing recommendation systems. For instance the open source Apache Lucene project which serves as a container for many popular algorithms. Though this thesis focuses on opening building shape to the thought model of cognitive science. Therefore we explore a novel kind of similarity calculation.

200 See chapter 13.5 for a discussion of this topic. See chapter 9.8 for a theoretical statistics module.

201 We use the past tense in this sentence, because due to the proliferation of machine learning algorithms in current research. Though machine learning always require vast data sets. If such a data set is not available in a problem domain then the results are often questionable.

not by a huge margin. It is often harder to follow the reasoning of a context aware system. The author hopes that a similar positive effect is also in place in this work.

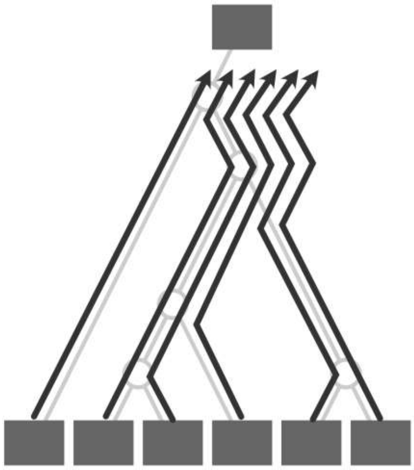


Figure 235: A visualisation of strong independence in the context of a Syntax Tree. Each initial numeric value takes its own way upwards. At the end a sum of all altered values is calculated.

By avoiding advanced statistics and machine learning it will be easier to follow and measure the effects of the parts that are central to this thesis: Sets of classification items custom tailored for architecture building shape, and some techniques from cognitive science like circumlocution in the Building Shape Periphrases (BSP) and Building Shape Syntax Trees (BSST)

We will add one more pattern called *Weak References* and will also measure if it adds value.

9.3. Weak References

Classification items are grouped in *sets*. These are well known data structure from computer science. Items in a set are distinct. An item with the same calculated identity can only exist once in a set. Items in a set have no particular order. Of course they might be viewed in a particular order like for instance by their alphabetical title but this is a special view and the ordering is more related to the view then the underlying unordered set.

Sets are an abstract logical concept and they can be implemented in different ways in a software. The technology used to persist sets for the current software implementation is the Web Ontology Language (OWL)[202] file format.[203] The term *ontology* is used here only in the context of logic and computer science. The use in philosophy and theory is

202 The World Wide Web Consortium (W3C) develops open standards like OWL https://www.w3.org/OWL/

203 In OWL terminology “items” are called “individuals” but this is often a confusing term when used outside of a specialized domain like formal logic, so we continue to call them items.

different and is not covered here. OWL and closely related technologies from *Semantic Web* and *Linked Data* research are capable to do far more then persisting and viewing simple sets. This is similar to a spreadsheet software application that often can do far more then adding up numbers. Though there is one concept enabled by OWL that we can benefit from: items can have *named relationships*.

In ordered data structured like lists, items have neighbours. One example: the letters in the alphabet. This is an implicit relationship. Sets do not have an order. A relationship can connects two arbitrary items in a set. An arbitrary hyperlink between two internet pages is an *unnamed relationship* and a machine can not infer its significance without a certain amount of error or use of statistics. A *named relationship* carries additional information like “hasSymptom”, “isCureFor” or “isLocatedIn”. An OWL file can define and constrain the named relationship.[204]

This enables Semantic Web software systems to infer additional information from available data and potentially allows to discover unknown correlations. Each named relationship also adds constraints and describes the connected items a bit more. For instance in a medicine scenario, items at the other end of a “isCureFor” named relationship can be inferred to be an *illness*, even when they are not marked up as such. A software part called a *reasoner* would throw an error or warning message if the information contradicts each other.

To make day to day work with OWL data easier we can define relationships as *reflexive* and *transitive*. *Reflexive* relationship are valid in both directions. When we apply A “isSiblingOf” B then it is automatically inferred that B “isSiblingOf” A. *Transitive* means that there can be hierarchies of named relationships with a common roots. For instance the named relationships “isSiblingOf” and a “isGrandParentOf” can be transitive sub properties of a “hasFamilyMember”. The sub properties inherit all constraints from “hasFamilyMember” and can add additional one.

Named relationships are not unique to OWL. In fact they can also be modelled in a traditional relational databases system. In OWL named relationships are first class citizens while in a database we must use helper constructs like foreign keys constraints and table joins. So called *property graph databases* would also be a valid match for this kind of data. Similar to OWL, property graph databases can attach a numeric or text value to

204 The use of the prefix “has” and “is” is a convention to better distinguish and OWL properties from OWL individuals/items. When OWL properties reference OWL individuals/items in the same OWL class they look similar to simple hyperlinks. The naming with the prefix in OWL are not enforced by the technology, but are a convention.

a relationship. The choice for OWL in the software implementation is more of a convenience then a strict requirement.[205] [206]

The benefits of named relationships are easier to follow with a simple example about building shapes. Lets take for instance the Tilt classification set like in Figure 177. When we assign a certain item to a Building Shape Periphrase, we make a decision to use this item over a neighbouring item. This is acceptable when we just want to classify one building, but when we want to compare building shapes with each other we might argue that building shapes that are annotated with tiltWidenSignificant (1) are closer related to other building shapes that are annotated with tiltWidenCompletly (2) then to some that are annotated with tiltTaperMinor (3) or tiltTaper (4).

The named relationships that we want to use to annotate our sets, are simple and they represent a stepped gradient:

- hasNoLink
- hasVeryWeakLink
- hasWeakLink
- hasNormalLink
- hasStromgLink
- hasVeryStrongLink

These named relationships are *reflexive* and have a *transitive* parent named hasLink. At a later stage in the software flow they will be quantified into numeric values. An advantage to model them by names rather then a numeric weight values is that we can fine tune the weights at a later stage. A disadvantage is that we are limited to a gradient of only six distinct values.

We call this group of named relationships *Weak References* in this thesis. We distinguish them from *direct matches* which can be interpreted as strong references.[207]

With our previous example of tiltWidenSignificant from the Tilt classification set we can observe the following:

205 There is a visual open source application called Protégé to edit OWL data. The desktop application Protégé serves approximately the same need as a spreadsheet application like LibreOffice Calc or Microsoft Excel does to work with tabular data.

206 The evaluation would change in favour for OWL when the software system would be extended with the Symmetry Phrase as discussed in 8.4. The features and inference of OWL/ RDFS would help modelling a Jackendoff style *smarter lexicon* in parallel to the “kick the bucket” example.The system is rather one of “fuzzy borderlines and family resemblance properties” (Jackendoff, 2010, p. 10).

207 We can see a parallel between Weak References and the Linguistic synonyms that Jackendoff would interconnect in his smarter lexicon. For instance “kick the bucket” as a synonym for “die”; its idiosyncratic meaning.

- tiltWidenSiginificant *hasWeakLink* tiltWidenMinor
- tiltWidenSiginificant *hasNormalLink* tiltWidenNormal
- tiltWidenSiginificant *hasStrongLink* tiltWidenCompletly
- tiltWidenSiginificant *hasNormalLink* tiltViewFormBelow

In a classification set like Tilt were there is an underlying logical linear order to the items this seems straight forward. It could be achieved by other technical means like counting the hops between elements. But the classification sets are custom tailored for architecture and not for geometry or formal logic. Therefore they have *Weak References* which are driven by an architecture experience. For instance they take into account real world things like gravity. All classification sets in this thesis have been created by the author of the thesis. The author decided that the following statement is required:

tiltWidenSiginificant *hasStrongLink* tiltWidenCompletly.

Instead of a *hasNormalLink* a *hasStrongLink* is used. This is driven by architectural practice. Gravity makes it hard but not impossible (see Canada Host Pavilion Montreal 1967) to have a distinct building part to tiltWidenCompletly and buildings that tiltWidenSignificant take a similar structural and material effort to achieve a similar visual effect.

Classification sets which are not implicitly linear in their layout[208] but rather planar or spatial can have more complex reasons for their weak references. One example is the Spacing classification set. Another example is the Proportion set which can conveniently be displayed as a five by five grid on a sheet of paper, but in theory it is a cube layout. Also the decision[209] that there is no strong distinction between front, left side, right side and back in the proposed system is modelled with the hasVeryStrongLink named relationship. Appendix B (19.2) documents all explicit named relationships.

9.4. Scoring

The similarity of two building regarding their building shape is calculated at two levels and additionally at the interface of these levels. We call one the *focus* building and the other one the *candidate* building. The process has the following phases:

- Periphrase Level: Each Periphrase from the focus will be compared to each Periphrase of the candidate. Memorizing each combination/permutation in an intermediate collection.

208 Sets do not have an explicit layout, but we often *view* them in a convenient layout/order, as it simplifies reasoning and organisation. This convenient order can be backed by Weak References.

209 See chapter 6.5.2 for the reasoning.

- Interface Periphrase to Syntax Tree: When there is more then one intermediate combination present then the best performing one will be identified and the other dropped.
- Synatx Tree Level: The score from the Periphrase level participates in the comparison at the Syntax Tree level. At this level the binary tree structure and a small set of rules influence the final score.

The final score is usually a number in the range of a few hundreds. As a number by itself it has no particular meaning. Each focus building has a theoretical maximum score. It can be calculated by comparing the building to itself. This number represent 100% similarity. Only a building with the exact same Periphrases and Syntax Tree can reach this number. Having a maximum score as a reference, we can take the candidate's final score and remap it to a percentage like *45% similarity*. By having percentages we can compare them to other results of other candidates with the same focus building.[210]

27 of the 80 World Exposition pavilions have been identified to consist only of one distinct building part. They have only a single Periphrase and no Syntax Tree in their persisted classification XML files. The software implementation compensates for this and will create a canonical representation that contains a Syntax Tree part. It is the most simple Syntax Tree possible, containing only one empty tree node. The canonical representation uses a helper node between the root node that symbolizes the real building shape and the Periphrase node. The new node is called a "NO OPeration" (NOOP)[211] node and enables the software to compare this shape with shapes that have an explicit Syntax Tree composition of more then one Periphrases.

9.5. Periphrase Comparison

The canonical representation of a Periphrase is made up of at least ten classification items distributed in the ten slots. The previous sentence says "at least ten" because it is valid to have multiple classification items from the same set in one slot. For instance a Periphrase might have a latticeTwist and a latticeBend at the same time in the Lattice slot.

The comparison at the Periphrase level is similar but simpler then the comparison at the Syntax Tree level, as no tree traversal is required. Only two rules apply in each slot and the final score is simply the sum of the ten slots.

The first rule is a distinction between direct matches and weak references. Direct matches, or weak references are identified. A direct match gets a score of 100, while weak ref-

210 For comparisons in the empirical part, we will use a different remapping. It will be discussed in chapter 12.

211 The abbreviation NOOP is common in software development to describe behaviour like this.

erences are multiplied by a penalty factor. E.g. hasStrongLink has a penalty of 25% therefore only a score of 75 remains.

- hasVeryWeakLink 90% penalty
- hasWeakLink 75% penalty
- hasNormalLink 50% penalty
- hasStrongLink 25% penalty
- hasVeryStrongLink 10% penalty
- direct match no penalty

The second rules is the *rule of significance* and it further alters the value. We will discuss the *rule of significance* in the section about Syntax Tree comparison in more details.

It is valid to assign more then one classification item from the same classification set.[212] For the Kaleidoscope this happens at the Tilt slot. The fact is a little bit hidden because the explicit assignment of the tiltViewFromBelow is annotated with behavior="ADD". Therefore the canonical representation of the Periphrase for the cylinder contains two values for the Tilt slot:

- The first is tiltViewFromBelow, which is also annotated to be "significant" and points out the fact that we can see the bottom of the cylinder.
- The second is the implicit default tiltApproximatlyNone. It describes the upright wall of the cylinder.

In a comparison the Kaleidoscope could be the *focus* building. It might very well be, that a *candidate* building has a Periphrase that contains also more then one value for the Tilt slot. In this case the software will calculate all permutations and pick the pair that together scores the most points. This theoretically applied to any number of focus and candidate items in the same classification slot. In practice there are only a few places where a three by three matrix is required, which needs to go through all the possible permutations. Currently there is no eminent need to optimize the software at this place. Appendix E (19.5) discusses this in more technical terms.

The permutation picks the setup that score the most points as a group. It might very well happen that the combined score of two medium scores (e.g. 60 + 60 = 120) beats a high performer together with a low performer (e.g. 100 + 10 = 110).

The same permutation calculation is also used at the interface between Periphrase and Syntax Tree.

212 See the section "Common ground becomes the multiassignment" in chapter 7.2.

9.6. Interface Between Periphrase and Syntax Tree

When the building shape of both, the *focus* and the *candidate* consist of only one Periphrase, then there is no problem to decide which intermediate result from the Periphrase should be used in the similarity calculation at the Syntax Tree level. But when either the focus building shape or the candidate building shape have a composition and therefore a more complex Syntax Tree then the system must pick the best performing combination of intermediate results. It must do this before continuing with the comparison at the Syntax Tree level. The software implementation is similar to the just mentioned necessary permutations in the Periphrase. But it goes a step further as it includes a *dry run* of each combination at the Syntax Tree level.

The *dry run* is a full Syntax Tree level similarity calculation. It is described in Appendix E (19.5) in more technical terms. The only difference to the final Syntax Tree level similarity calculation is, that the *rule of composition push* is explicitly turned off. Each possible combination of the intermediate collection of Periphrase results is calculated and the highest scoring setup is determined. The other potential setups are dropped.

The interface between Periphrase and Syntax Tree solves similar problems like the Linguistic interface in Jackendoff's *Parallel Architecture* as depicted in Figure 10. “An interface communicates only certain aspects of this information to the next level up- and downstream" (Jackendoff, 2002, p. 6)

9.7. Syntax Tree Comparison

9.7.1. Matching Classification Items

The matching of classification items at the Syntax Tree level, is the same as in the Periphrase level. Direct matches and weak references work in the same manner. Though we have a different group of classification sets. Also we have the special values from participating Periphrases that made it through the interface filter.

9.7.2. Bubble up

The binary tree structure that makes up the Syntax Tree allows us to alter the score of a matching item as we follow the path it would take to reach the root node at the very top. The top node represents the entire building shape. In software development such a tree path traversal is often referred to as “*bubble up*”. When a score bubbles up, it passes by junction nodes. We can alter its value by inspecting if certain rules apply at each node.

Because we inspect if a rule applies at each tree node independently we can take advantage of *recursion*[213]. This is one of the central inspirations from the interdisciplinary chapter about cognitive science. Similar to linguistic syntax trees the context for a node is small. It is the incoming value with its significance attribute and the nature of the incoming axis it bubbles up on. This small context and recursion allow that the rules themselves are simple.

The following bullet list will define relevant terms. We will be able to use these terms in a list of rules. Most of the terms are already introduced earlier in this thesis, but are repeated here for a simpler overview.

- *Match* – When we compare two Syntax Trees we will find that certain classification items are the same or at least connected via weak references. They *match* and get an initial score assigned. A special kind of *match* is the best performing Periphrase score that we introduced in the previous section.
- *Root* – As the Syntax Tree is visualized upside down the *root* is at the top and symbolizes a distinct real world building shape.
- *Leaf* – At the bottom of the tree are classification items and placeholders for the Periphrases. They are the *leafs* of the Syntax Tree and they are the points where a *match* starts to bubble up.
- *Join* – Nodes in the middle of the tree where two branches meet, are neither *leafs* or *root.* Depending on the point of view, they are usually called *forks* or *joins*. As we use the “bubble up” analogy we will stick with the term *join*.
- *Headed* – Each join is *headed*. This means that one incoming lower branch is considered more important then the other incoming lower branch. It is *dominating* the other branch. This is visualized in a way that the dominating branch continues as a straight line, while the dominated branch terminates at the join.
- *Dominated Axis* – Each dominated branch is associated with an axis that can be either short or long, but leads in a straight line to a *leaf*. This is a *dominated axis*.
- *Significance* – When a *dominated branch/axis* terminates at a *join,* it can be annotated with a *significance* attribute. This modifier represents the importance of all leafs below.
- *Main Axis* – The axis that connects the *root* node with the rest of the binary tree structure is called main axis.
- *Noop Node* – Noop stands for “No Operations” and is added by the software to create minimal canonical Syntax Trees. So building shapes that consist of a single distinct

213 See Glossary in chapter 2 and chapter 8.1 for *recursion* in the context of the Syntax Tree.

building part can be compared to building shapes that have a real composition. Noop nodes are special as they are positioned automatically in between the *root* and the single *leaf* and have no branching.

We want to take advantage of the tree structure and its parts to get better results when comparing two Syntax Trees. A “strong independence” assumption is in place.[214] The approach is similar to a Naive Baysian model[215]. We look at each match independently and change its value while it bubbles up the tree. At the end we sum up all the values that arrive at the root. The amount by which a value is altered at each join or noop node is determined by a handful of rules.

9.7.3. Rules

A rule takes an incoming numeric value that is bubbling up the tree structure and modifies it to an outgoing value.

The self-comparison score is the value that a comparison of the building shape against a copy of itself would score. It represents a maximum. No other comparison should score a higher value. We will use the term “self-comparison” in the text to refer to this requirement. We use the term “self-similarity” throughout the thesis to refer to similar looking distinct building parts and their Periphrases[216]

Modifications to the numeric values that happen on *joins* are always *penalties*. In some cases there is a penalty of 0% and the outgoing value is equal to the incoming value, but in many cases there is a penalty and the outgoing value is smaller. The rational that there are only penalties on joins and no bonuses is that there should never be a building shape that has a final score higher then the self-comparison score. In an unfortunate constellation a rule that grants bonuses at a join might lead to a final score above the maximum.

At leafs it is also possible to have *bonuses* as well as *penalties*. This happens for instance the *rule of composition push*. The different behaviour is possible because this rule triggers only at the start leaf and never at a join, therefore the important self-comparison is guaranteed to benefit from it as much as any candidate might.

The penalty numbers are represented as percent values. In the current implementation the initial values are determined in an iterative manual trial-and-error processes and

214 For a visualisation see Figure 235 . A related more formal term in Artificial Intelligent research is *conditional independence*.

215 Artificial Intelligent researchers acknowledge the surprising performance of Naive Bayes models

> [...] a naive Bayes model—“naive” because it is often used (as a simplifying assumption) in cases where the “effect” variables are not actually conditionally independent given the cause variable. [...] In practice, naive Bayes systems can work surprisingly well, even when the conditional independence assumption is not true. (Russell and Norvig, 2009, p. 499)

216 We discuss self-similarity with the example of A4 - Expo 2010 Russia Pavilion (Shanghai) in chapter 8.3.

influenced by subjective architecture experience. We will find that the numbers are often straight integers like 90%, 75%, 50%, 25%, 10%. This makes it easier for a human to follow the reasoning and scale of a penalty. We can assume that these are not the optimal numbers. Future implementation could alter the values. When more model data and empirical data would be available it could be possible to let a computer program calculate the optimal values. Unfortunately this is out of scope for this thesis. Appendix E (19.5) discusses this in more technical terms.

When no of the below rules is triggered then the outgoing value is the same as the incoming value. This can be observed when a bubbling up incoming value arrives at a join from the dominating sub branch and continues to bubble up in a straight line.

The following rules are implemented, and are described below:

- Rule of Dominance
- Rule of Significance
- Rule of Composition Present
- Rule of Composition Push

Rule of Dominance

This is the most basic rule. It can be overridden by the more complex *rule of significance*. The rule is triggered when a bubbling incoming value arrives at a join from a dominated branch that terminates at this join. The rules applies a penalty of 50%. So an initial value of 100 that passes by three joins where this rule is triggered would shrink to 50, 25, 12.5.

Rule of Significance

It is considered at the same places like the rule of dominance. When it is triggered than it overrides the rule of dominance at this join. The rule is triggered when a bubbling incoming value arrives at a join from a dominated branch that terminates at this join. Additionally the bubbling value must originate from the leaf on the other end of the dominated axis.

The rule looks at the data model of the focus tree as well as at the data model from the candidate tree. On the Syntax Tree of the candidate it looks up the leaf that is responsible for the match. This can be a direct match or one via a weak reference. Then it bubbles up to find the very similar join in the candidate Syntax Tree where the axis of the leaf merges into a more dominated one. It inspects this join for a significance attribute. The four possible significance values it can encounter are:

- significant
- normal – this is the default value when a distinct value is missing

- inferred – this value appears when the leaf was created by the software to fill the gaps for a canonical representation.
- minor

The same inspections of the significance attribute now happens back at the focus Syntax Tree at the node where we are bubbling up. This leads to a pair of significance values. One for the focus and one for the candidate. The penalty is looked up by locating the value in the following table:

Left: Candidate Bottom: Focus	Significant	Normal	Inferred	Minor
Significant	0% **	20%	40%	60%
Normal	50%	50% *	60% ***	70%
Inferred	70%	70%	70%	80%
Minor	90%	90%	90%	90% ****

We can see that the table is not symmetrical on its diagonal. It does matter if a building is the *focus* or if it is the *candidate*. The behaviour is no reflexive. This is driven by the requirement that no building should score a higher value then the self-comparison. The focus clamps the value that the candidate can achieve on the left side of the diagonal of the table.

When we inspect the table, we can make the following observations[217]:

- * the combination of Normal-Normal has a penalty of 50% which is the same as the one in the *rule of dominance*.
- ** the combination of Significant-Significant has a penalty of 0%. Therefore when both, the focus Syntax Tree and the candidate Syntax Tree, considered this match from the same classification set significant the value contributes more.
- *** Combinations that contain “Inferred” like Normal-Inferred have a slightly higher penalty then the Normal-Normal, because the system assumes that data added implicitly by the software to complete the canonical representation must be less important than data added explicitly by a person.
- **** The Combination of Minor-Minor has a high penalty of 90%.

217 A slightly adjusted version could be represented by a formula. Such formulas could be optimized in future research, but this is currently out of scope. Same as the table in Rule of Composition Present

Rule of Composition Present

This Rule exist because composition can be present or absent. And comparing a focus building with a candidate building were this differ must have an effect.

The rule triggers when the value bubbles up and hits a *noop* node or merges into the main axis. In the second case the rule does a further check on the main axis which it just reached. It looks for the join on the main axis that is the closest to the root. It might very often be the case that this is the same join that the value just arrived, but for a few cases there might be a join further up. There is a constraint on the data models that joins with a higher significance must merge higher into an axis then joins marked up with a lower significance. This follows the sequence: significant, normal, minor.[218]

By looking to the join on the main axis closest to the root we can find out the highest significance attribute of a composition related to Periphrases in the Syntax Tree.

We need the same information from the candidate Syntax Tree. There we start at the leaf and not already at the main axis, so we need to ignore all intermediate joins on the way up and stop at the very last join before the root. Or we might have a noop node as a return value.

Now that we have the two values we can look up the penalty in the following table:

Left: Candidate Bottom: Focus	Significant	Normal	Minor	Noop
Significant	0% *	10%	25% ***	40%
Normal	10%	0% *	10%	25%
Minor	25%	10%	0% *	10%
Noop	40% **	25%	10% ****	0% *

When we inspect the table, we can see that it is symmetrical on its diagonal. Additionally we can make the following observations:

- * Combinations of the same value have a penalty of 0%. This is important so a self-comparison gets no penalty but every other combination at least a small one.
- ** The combination of Significant-Noop gets a strong penalty of 40%. The rational is explained with the example of the Russia pavilion versus the Canada pavilion.

218 Note that the "inferred" is missing from the sequence: significant, normal, minor. This is due to the fact that at least one Periphrase that will merge into the main axis must be specified by a person to have a composition tree that is not a *noop node*. All other composition level classification items might be inferred by the software to have a complete canonical tree, but they merge into the secondary axis. As this rule only triggers on the main axis, there can never be a significance of "inferred" in this setup.

- *** The combination of Significant-Minor gets a penalty of 25%. The rational is explained with the example of the Russia pavilion versus the Japan pavilion.
- **** The combination of Minor-Noop gets a modest penalty of 10%. The rational is explained with the example of the Canada pavilion versus the Germany pavilion.

We can compare a building where there is only one distinct building part and therefore no composition, with one where the composition is important. For instance the “A1 - Expo 2010 Canada Pavilion (Shanghai)” (Figure 236) as the focus and the “A4 - Expo 2010 Russia Pavilion (Shanghai)” (Figure 237) as the candidate. Obviously they have some building shape properties in common. But looking at only one of the Russia towers and comparing it to the whole Canada building would ignore the fact that the Russian building has a strong composition and a central hall. Therefore a strong penalty of 40% is applied.


Figure 236:
A1 - Expo 2010 Canada Pavilion (Shanghai)


Figure 237:
A4 - Expo 2010 Russia Pavilion (Shanghai)


Figure 238:
F2 - Expo 2010 Japan Pavilion (Shanghai)

The example where we compare a building where the composition is important, with an other were the composition is only of minor importance is a bit more complex. For instance the “A4 - Expo 2010 Russia Pavilion (Shanghai)” (Figure 237) and the “F2 - Expo 2010 Japan Pavilion (Shanghai)” (Figure 238). The Russia pavilion has a strong composition, but the Japan pavilion has only a small integrated annex part and it’s main distinct building part does not have many properties in common with the Russia pavilion. Still we would get some matches between the Japanese annex building part and the Russian central hall. We would assign a penalty of 25% from this rule. This penalty is even on top of the other penalties, like the one from the rule of significance.

The third example is the “A1 - Expo 2010 Canada Pavilion (Shanghai)” (Figure 236) which consist of only one distinct building part and the A2 - Expo 2010 Germany Pavilion (Shanghai) (Figures 239, 240 and 241) which has one big zig zag distinct building part at the top and a base. The base is less important and hard to recognize. The base is marked as *minor* significant in the data model of the Germany pavilion[219]. Only a modest penalty of 10% is applied.

219 The fact that the German pavilion has one distinct building part which is bend can be seen better from an aerial point of view. It was one of the most challenging building shape of the 80 World Exposition buildings.


Figure 239: Pedestrian Front View. This is the view most visitors will encounter.

A2 - Expo 2010 Germany Pavilion (Shanghai)


Figure 240: Pedestrian Back View. The “brown” structure is the base on which the zig zag structure is placed on.

A2 - Expo 2010 Germany Pavilion (Shanghai)

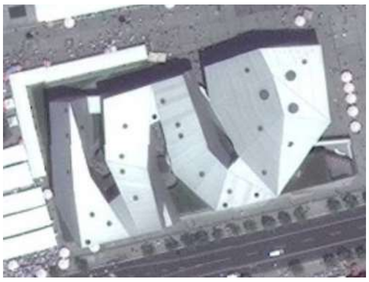


Figure 241: Aerial. The zig zag shape of the top distinct building part is recognizable.

A2 - Expo 2010 Germany Pavilion (Shanghai)

Rule of Composition Push

The *rule of composition push* is applied to all classification items from the Syntax Tree level. This includes: Spacing, Cardinality, Orientation, Relative Size, Size Randomness and Variety. The rational for this rule is the following: Periphrases contains ten slots with potentially ten or more values that contribute scores. Even a default match of inferred versus inferred contributes 30 points inside a Periphrase. We often have two or three Periphrases. In a hypothetical example: It is not seldom that effectively 16 classification items contribute from the Periphrase, but only 4 from the Syntax Tree. They all start with the default value of 100. The 4 Syntax Tree level classification items are further degraded because they bubble up through the Syntax Tree and often get penalties. To compensate for this disadvantage we push the 4 values by a multiplier / bonus.

The current approach used for the push is: 50% of the leaf level contributions must come from Syntax Tree classification items.

We can see the push happening in the applied canonical example of the Kaleidoscope and the Saudi Arabia pavilion in Table 7 in the next chapter. We will repeat it here in a textual form:

	before push	push factor	after push	final
First Periphrase	390		390	351
spacingGapPartial	25	147% bonus	61	3
card2	100	147% bonus	247	2
orientationVerticalDown	100	147% bonus	247	9
sizeSmallerSignificant	100	147% bonus	247	12
Second Periphrase	415		415	41

We can see that *before the push*, the two Periphrases contribute 805 points, while the four Syntax Tree level classification items contribute only 325. *After the push*, the values from both groups are the same: 805 versus 802[220]. At first glance, it might look like the rule significantly favours the four Syntax Tree values. But when we look at the *final* column, we see that their final contribution is relative small. It is actually only 6% of the overall final score. This is due to the fact that the values bubble up the Syntax Tree and get high penalties at various joins that they pass. This is especially true when the second distinct building part is of *minor* significance in the *focus* as well the *candidate* building. This is the case for the Kaleidoscope and the Saudi Arabia pavilion. We can look at an example where the Syntax Tree is of normal importance, like in "C1 - Expo 2010 Angola Pavilion (Shanghai)" vs. "C2 - Expo 2010 Algeria Pavilion (Shanghai)" (see chapter 10.5). Even there the final contribution is a modest ~12% of the final score.

There is potential to further fine tune this arbitrarly picked "50%" constant, by inspecting its effect on the whole data set. Values of 33.3% and 25% as well as some initial tests with values higher then 50% have been done, but the full implications must be studied. Its could also be possible to make the value be more context aware. It would vary based on the *focus* and *candidate*, rather then being a global constant. For instance instead of simply working on the point values that are present in the leafs, one might count the actively contributing classification items from each layer. For instance 16 versus 4. This fraction could drive a first multiplier. The second context aware number could be the average amount of join nodes that a Syntax Tree classification items will pass and let it drive a second multiplier. In theory each multiplier could be modelled as a separate rule, which makes it easer to reason about.

The four rules that we just elaborated on, use common software infrastructure and abstractions. Future version might include more rules based on additional assumptions. One potential source for new rules is statistical data which we will discuss in the next chapter.

9.8. Statistical Module

This chapter discusses the potential of a statistical module that improves comparison of building shapes. A more general discussion about current trends in research, and how this thesis positions itself, can be found in chapter 13.5. The more applied concepts of this chapter can be seen as parts of a *hybrid* system. The statistics in this chapter are *traditional* in the sense that we assume that they are aggregating information on a data set of a few thousand entries. Current trends like *machine learning* and *probabilistic statistics* require much bigger data sets and are not considered here.

220 The missing 3 is due to the rough cut of all decimal values for presentation purposes in tables in this print document. Of course the software takes further decimal values into account.

Because the empirical data set contains only 80 buildings there is no implementation of a statistics module in the software that has been used in this thesis so far. At this stage this remains a theoretical, but promising addition. For this chapter we assume a hypothetical complete data set including each and every pavilion ever build on a World Exposition site. Such a data set would contain a few thousand buildings.

The person editing the building shape classification is assigning the *significance* attributes. So it is up to human judgement to decide what is important. This will always be to a certain degree subjective. In a small set of only 80 buildings this could be a valid approach. It allows to make the scope of a research project manageable.

Is there a workaround? To avoid the need to mark up thousands of buildings before statistical results are relevant an alternative approach could be chosen. Instead of counting the real instances one could assign meta data to the classification items if they are *common* or *seldom* with a weighted numeric value. Even though far easier, this approach would be potentially very biased. It gives the person that applies the values some great responsibility. It would also be hard to do this task in advance for combinations of properties like the curvatureConvexConvex (synclastic) plus curvatureConcaveConvex (anticlastic) from the F3 - Expo 2000 Japan Pavilion (Hannover) (Figures 160, 161 and 162). A combination might be more interesting then a single value. The automated calculation of real statistical data might enable us to find more interesting hidden insights. So we dismiss such workaround.

In a setup with a few thousand buildings we could replace or augment human judgement with statistical information. For instance if the F3 - Expo 2000 Japan Pavilion (Hannover) is one of very few buildings that have curvatureConvexConvex (synclastic) and curvatureConcaveConvex (anticlastic) Curvature at once, the software could infer an additional attribute by itself. We will call this theoretical attribute *seldom*.

Such statistical systems are not unbiased by themselves. They usually have a *closed world assumption* and can only act on the data available. The following phenomenons might emerge:

- Buildings in the shape of a nearly full sphere are not that seldom on World Exposition sites.[221] At a second thought this is not surprising, because this shape can

221 For example:
Perisphere, New York 1939,
USA pavilion, Montreal 1967
Germany pavilion, Osaka 1970
Identity structure, Sevilla 1982
Romania pavilion, Shanghai 2010
Azerbaijan pavilion, Milano 2015
Main pavilion ,Astana 2017.
Transformed or composed spheres include:
Atomium, Bruselles 1958
Bertelsmann pavilion, Hannover 2000

symbolises the globe or is often associated with coherence. But outside of World Exposition sites this shape is very rare (Paris Geode, Kugelhaus Wien, Kugelhaus Dresden). "Outside of World Exposition sites" is a vastly bigger data set of buildings.

- The Expo 2010 in Shanghai hosted a significant number of pavilions with always the same building shape. This allowed a lot of nations to be represented in an own pavilion. They differed mainly in colour and decoration. So this would now constitute the most common building shape for a World Exposition pavilion. We will later discuss this as the "hidden-simple" group in chapter 10.5. and as empirical data in chapter 12.1.
- The layout of the World Exposition site in Milan 2015 contained two major axis and most of the pavilion sites were narrow strips of land therefore many pavilions are following these proportions. A long stretched proportion is now not seldom any more.
- Loosely clustered distinct building parts connected by some common infrastructure were quite seldom. For instance: "D2 - Expo 1967 Africa Group Pavilion (Montreal)" and "D6 - Expo 2010 Netherlands Pavilion (Shanghai)". But the Expo 2015 in Milan had eight group pavilions that followed a cluster pattern and additional nation pavilions and organisation pavilions (Bahrain, Netherlands, Turkey, Caritas, United Arab Emirates) that followed this design idea.
- There are only very few pavilions that are a rectangular box with a gable roof on top of it. "Outside of World Exposition sites" this is a very common building shape. We face an ambiguity if this is *seldom*.

Still if the hypothetical "complete data set including each and every pavilion ever build on a World Exposition site" is the proclaimed scope of a research project then these statistics are correct. And it might be acceptable that they shift with every World Exposition that is added.

Dealing with statistical values like calculated *seldom* attributes is not challenging for a software system. The calculation might require some computational resources, because the whole data set must be analysed with aggregation. As long as the data set is in the quantities of a few thousand, contemporary hardware and software of a single computer should be sufficient. Depending on the user performance expectations, these values can be precomputed each time a building shape is added, or calculated on the fly and cached on first use. The mathematics required for the calculation is also well known.

Malaysia pavilion, Milano 2015

Serpentine Gallery pavilion 2006(El-Khoury, Payne and Riera Ojeda, 2010)

We can identify a few potential places where new rules based on *seldom* might play a positive role:

- *single-seldom-item rule* - A simple rule that pushes matches with seldom used classification items.
- *seldom-combination-of-items rule* - A more advanced rule that pushes seldom combination of matches of pair/triples/quadruples/... across classification sets within either a Periphrase or a Syntax Tree.
- *seldom-combination-crossing-interface rule* - A complex rule that pushes seldom matches of pair/triples/quadruples/... across classification sets which bridge the interface between Periphrase and Syntax Tree.

The next paragraphs will outline each of the theoretical rules.

single-seldom-item rule

We have ten slots in a Periphrase and each slot contributes within the same range of 0 to 100 points. This amount is mostly controlled by the *rule of significance* which we discuss earlier. A new simple rule that is based on statistics would work in the following manner:

- During a comparison calculation of two building shapes there is a directMatch / hasVeryStrongLink / hasStrongLink in a classification item that is seldom used within all building shapes. As a hypothetical example: in the *edge* classification set we have the value of edgeFillet which is used to described rounded soft edges.
- We argue that there are only very few buildings that use edgeFillet so a match is *something special.* Both building shapes in the comparison use edgeFillet. This is *seldom* and should be *pushed.*
- Rather then applying a penalty like the rule of significance, we would apply a bonus of f.i. 100%.
- Bonuses must always be used cautiously, because no building shape pair should reach more then 100% similarity. The proposed bonus should by acceptable, because the self-comparison calculation would also benefit from the same bonus. We would simply increase the maximum point value that defines the 100%. Though it must be implemented with caution because it will push the potential maximum value higher. This might has negative implications. We will see this problem reappear again – even stronger – in the next rule.

The *single-seldom-item rule* can work for a classification item of a Syntax Tree in the same manner as in the Periphrase.

Our canonical example, the Kaleidoscope compared with similar buildings like the Saudi Arabia, Quebec, Canada Host or China Host pavilion[222] might benefit[223] from a seldom orientationVerticalDown classification item. The new rule could be further enhanced when weak references are utilised as well. The Kaleidoscope comparisons would also gain some smaller bonus in the Tilt slot, where tiltViewFromBelow can be associated with tiltWidenComplete (hasStrongLink) or tiltWidenSignificant (hasLink)

The *single-seldom-item rule* should also be compatible with the “strong independence” pattern that we use. If there are additional single-seldom-item matches in other independent slots, they simply get an independent bonus.

seldom-combination-of-items rule

A potential *seldom-combination-of-items rule* differs from a *single-seldom-item rule* by looking at the statistical information for a pair of classification items. Within a Periphrase we would permute all slots that contribute values greater then zero and form pairs. We might further filter out all implicit matches and only allow explicit matches which would significantly reduce required calculation effort. Pairs might be from different slots or even from the same slot. For instance the F3 - Expo 2000 Japan Pavilion (Hannover) has two values in the Curvature slot: curvatureConvexConvex and curvatureConcaveConvex.

We work at the classification item level. For instance it might be seldom that a curvatureUndulation and a featureHighPoint are present at the same time in both buildings shapes that we compare.

A further enhancement would be when we would utilise *weak references* as well. We would not only apply bonus to direct matches, but also some smaller bonuses to hasVeryStrongLink and hasStrongLink. This is analogues to the *single-seldom-item rule.*

A software system is doing the tedious work, and the potentially expensive statistical information is a one-time-calculation that can be cached or precomputed. We might extend the system from pairs to triples to quadruples and so on. In theory we could take all ten slots of a Periphrase into account. Though this would make it harder for a human to follow the system.

We need to be cautious with the important self-comparison calculation that delivers the maximum number of points that define the 100%. If a building shape is uncommon, then most likely the combinations of its slot values are seldom. But compared with itself this would lead to a lot of matches and the maximum number of points would increase. This would quickly sum up. To understand the effect lets assume that this new rule

222 Some of these combinations are actually the examples of chapter 10.

223 This is a “gut feeling” and not proven. Within the 80 buildings we have exactly these curated group E “cantilever”, so the seldom-values-statistics are distorted.

pushed suddenly the self-comparison of the Kaleidoscope from 725 to 1450 which now defines the 100%. Then buildings that score 420 points like the Saudi Arabia pavilion would not be 57% similar, but only 27.5% similar. Of course the Saudi Arabia pavilion would also gain some points from the new rule and the gap would close. Though not at the scale like the self-comparison.

A counter measure for the self-comparison problem might be to include a threshold that filter out outliers. The self-comparison being the biggest outlier itself. For instance the bonus is only applied if the pair is not *unique* but *seldom*. Maybe it kicks in when this combination is present in at least two/three/four/five building shapes. The self-comparison would be one of the five, therefore it would benefit from the bonus like the other four. The base assumption that no other building shape should score more then the 100% of the self-comparison would hold true.

seldom-combination-crossing-interface rule

The poorly named *seldom-combination-crossing-interface rule* would be an extension of the *seldom-combination-of-items rule* as it would allow classification item pairs to be formed across Periphrases and Syntax Tree. This might be attractive for cases like the canonical Kaleidoscope example: tiltViewFromBelow from the Periphrase, and orientationVertical-Down from the Syntax Tree. Though the complexity is hidden in the calculation at the interface between Periphrase and Syntax Tree (see also chapter 9.6). Because it would require the result from the interface permutations and at the same time influence it. This cyclic dependency is challenging to implement and might exceed its benefits.

This chapter outlines three potential rules that are based on statistics. This is by no means an exhausted enumeration. Once the software infrastructure of a statistical module would be in place, additional rules might be discovered and tested.

10. Examples of Building Shape Comparison

The previous chapter is theoretical. This chapter tries to make the process tangible by comparing our canonical example building Kaleidoscope with four other pavilions from the curated "cantilever" group.[224] The last fifths example are buildings from the curated "hidden simple" group[225]. We pick comparison pairs that are also part of the empirical data gathering.

Visualising the comparison in a print layout like this text document is challenging.

In an interactive HTML5 setup, which was used as an internal analysis tool this is significantly easier. In an interactive setup parts of the information can be hidden while the print publication must show all information. In print this must happen in a way that is readable. Therefore the print layout requires up to seven table/figure pages per comparison. This layout allows text notes without to much abbreviation for each Periphrase slot. To achieve this each Periphrase comparison is split up onto two pages.[226]

Each comparison starts with a page with photographs of the two pavilions on a single page, so the reader can have a first visual impression.

To better understand the print page layout – and not get lost – this chapter will start with a few explaining diagrams. We will repeat Figure 60 in Figure 242 as it is the central conceptual diagram. The following Figures 243, 244 and 245 are simplified abstractions of this conceptual diagram.

224 See the group E "cantilever" in chapter 12.1.5 for the related empirical data.

225 See the group C "hidden simple" in chapter 12.1.3 for the related empirical data.

226 This allows to have 5 columns per page rather then 10. 10 columns are hard to read in print.

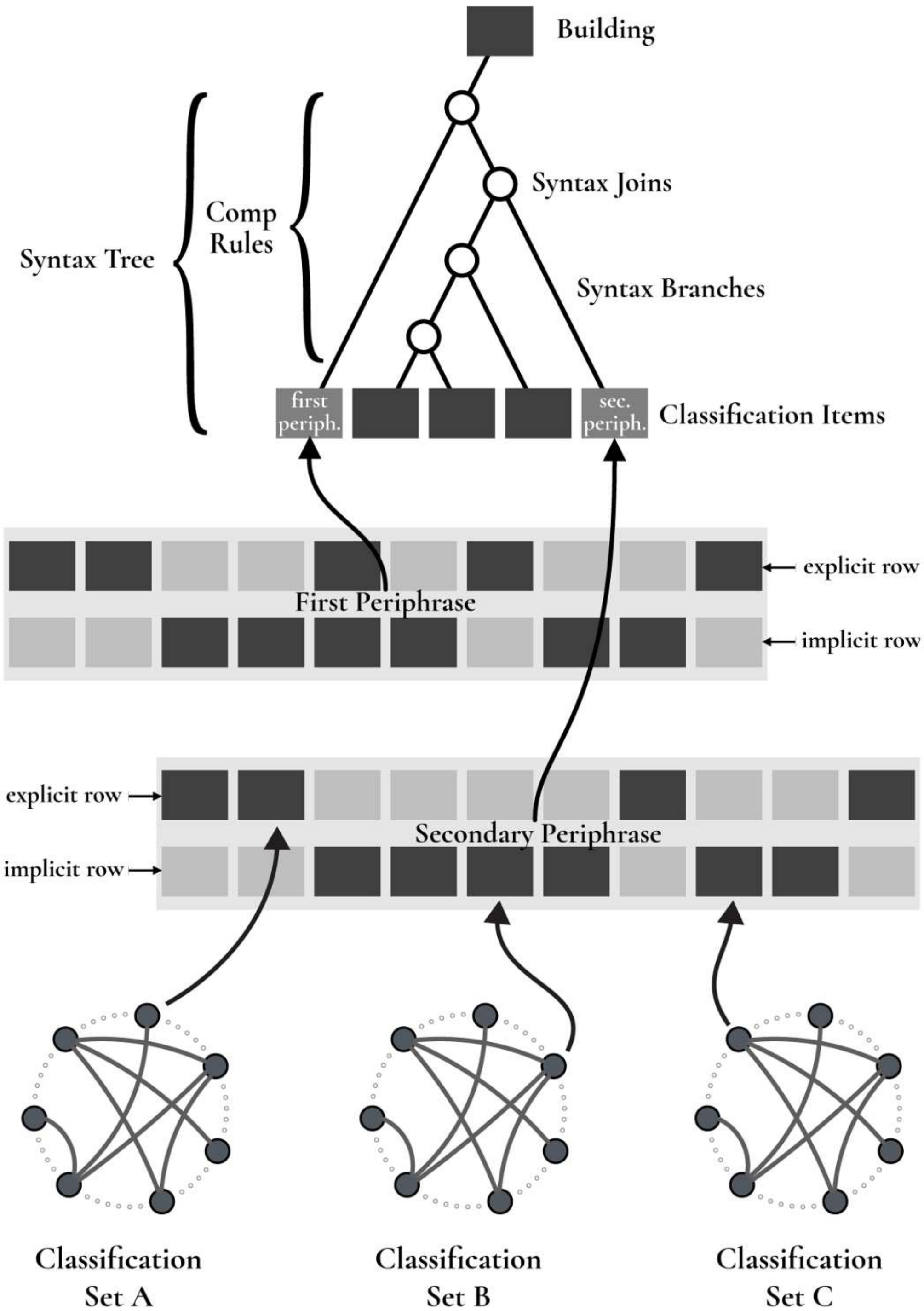


Figure 242: Visualisation of the proposed classification system, with the connections between the different layers. Building Shape Syntax Trees (top) Building Shape Periphrase (middle), Classification Sets (bottom), and Named Relationships (arcs within Classification Set circles)

After the photographs, each comparison continues with two screenshots from Appendix A (19.1), like in Table 1. Please be aware that in these screenshots the *implicit row* and the *explicit row* are compressed into a single row. The explicit classification items are the black icons, while the implicit classification items are the light grey icons. In detailed diagrams like Table 3 we will use separate rows for implicit and explicit data similar to Figure 242.

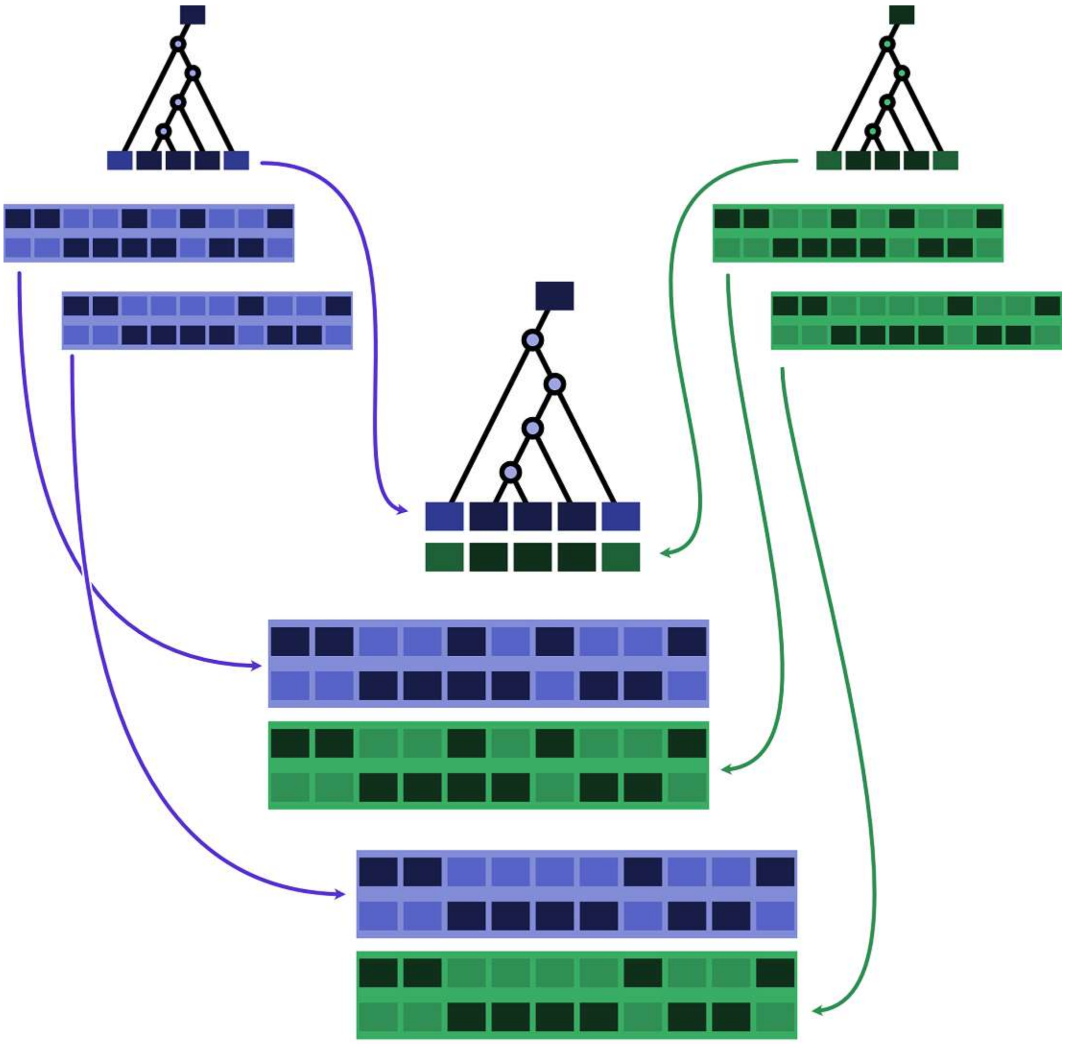


Figure 243: We will use colour coding for the purpose of explaining the diagrams and throughout the chapter. We compare the blue "focus" building with the green "candidate" building. We interweave the two diagrams into one. The aim is to better co-locate and correlate classification sets. Classification items from one set form a "column of four" in the Periphrases. In the Syntax Tree we only display the syntax tree of the "focus" building and have only "columns of two" due to print layout limitations.

Figure 243 introduces "column of four" for each Periphrase slot. Please be aware that this a simplification. The system allows that there is more then one classification item available per slot, therefore we will also see "column of five". The Periphrase for E1 – Canada Host-Pavilion 1967 has even three items in the *Feature* slot, which is a visualisation challenge.

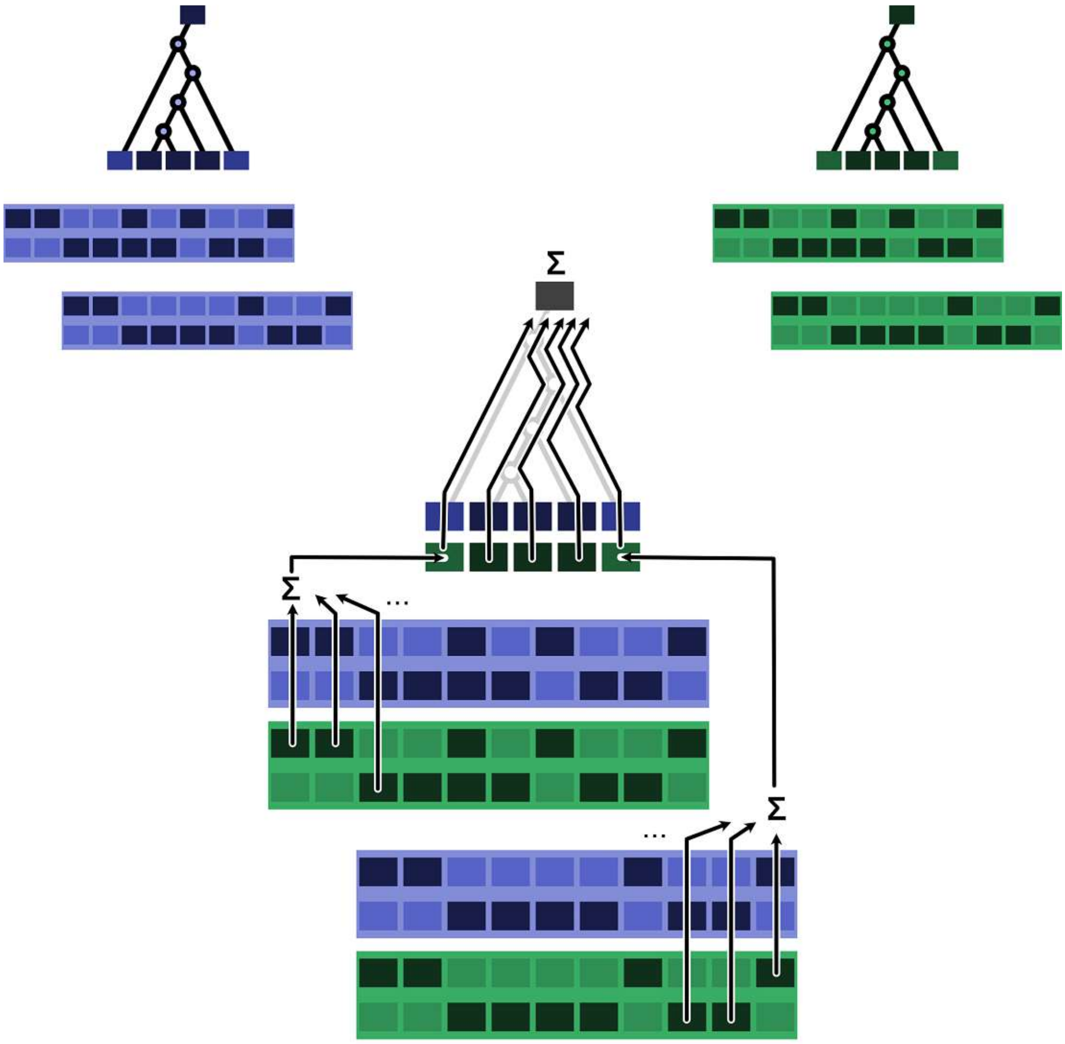


Figure 244: We inspect each "column of four" in the Periphrases. We can follow the flow of the initial numeric value and see how different rules apply and how penalty multiplier decrease the numeric value. In each Periphrase we add up the numeric values into one sum. This sum value is then propagated into the Syntax Tree digram. Here we repeat the flow of the numeric values, but this time it happens along the axis of the syntax tree. At each node where one dominated axis merges into a dominating axis we will see the value being altered by rules. At the top of the digram we will again sum up all the bubbled up values and have a final "score".

We will follow values from the bottom up to the top as described in Figure 244. The values are abstract numeric values, starting with an initial value of 100. For readability all numbers are rounded to whole integer numbers and all decimal information is omitted. The rounding is a hard truncation to their floor value. For example a "1.9999" is shown as "1". Of course the real implementation takes the decimal numbers into account.

At the end we have a final score; for instance 420. This number needs to be remapped so it is easier to interpret it when we look at other pairs. We will transform it into a percent number, by taking the self-comparison[227] into account. The self-comparison is a comparison of a building against a copy of itself and it represent a maximum value. For the Kaleidoscope this value is 725. A similarity result of 420 can be expressed as 57%.

227 See chapter 9.7.3.

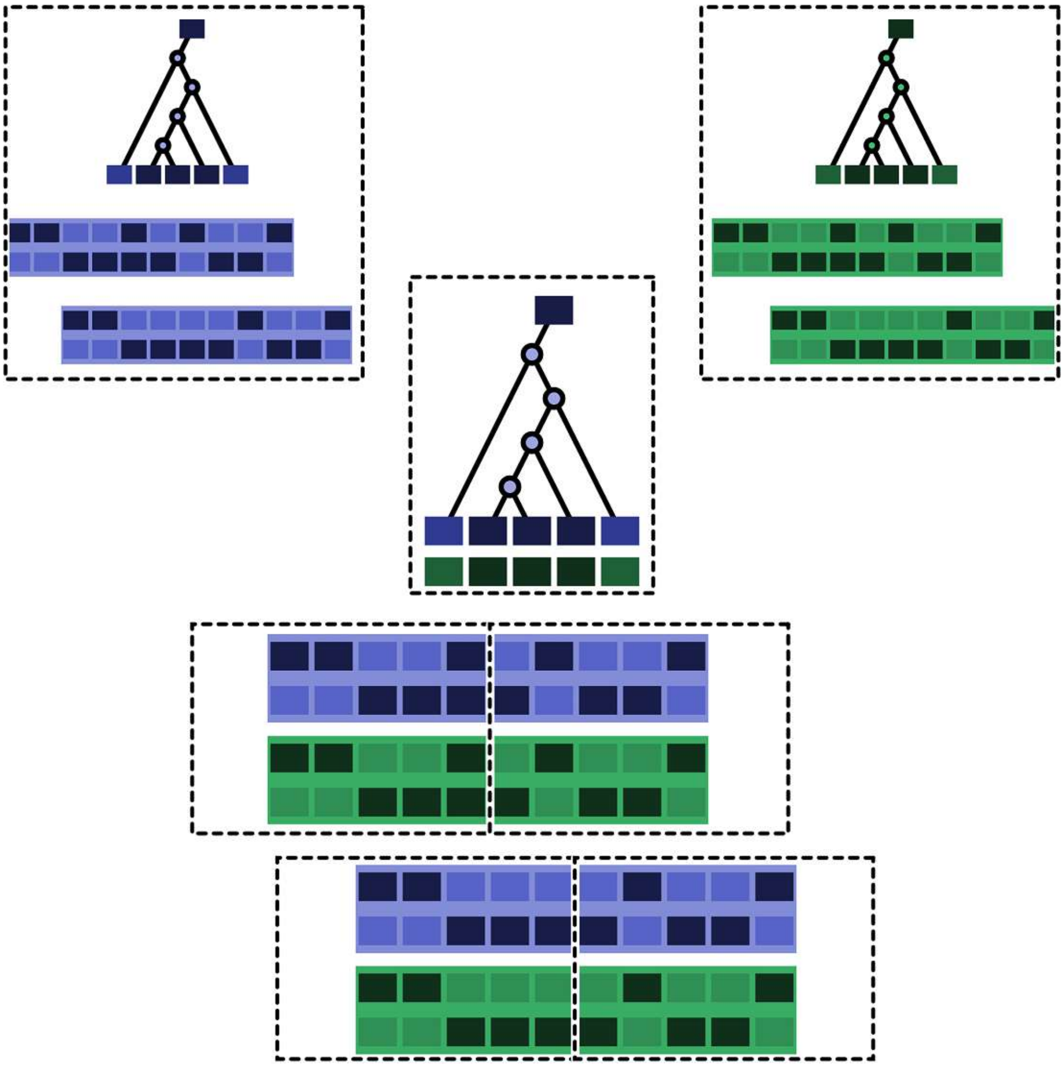


Figure 245: Due to the limitation of a static print/PDF layout versus an interactive HTML5 layout we will require quite a few print pages for each comparison.

- Page A - Classification data of the "focus" building as it appears in Appendix A (19.1)
- Page B - Classification data of the "candidate" building as it appears in Appendix A (19.1)
- Page C – First Periphrase(s); First five "columns of four"
- Page D – First Periphrase(s); Second five "columns of four"
- Page E – Second Periphrase(s); First five "columns of four"
- Page F – Second Periphrase(s); Second five "columns of four"
- Page G - The Syntax Tree of the "focus" building and the bubbling up of the values from the "candidate" building

10.1. Kaleidoscope and Saudi Arabia Pavilion

Focus Building: E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)

Figure 246: E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)


Figure 247: E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)

Figure 248: E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)

Candidate Building: E4 - Expo 2010 Saudi Arabia Pavilion (Shanghai)


Figure 249: E4 - Expo 2010 Saudi Arabia Pavilion (Shanghai)


Figure 250: E4 - Expo 2010 Saudi Arabia Pavilion (Shanghai)

Figure 251: E4 - Expo 2010 Saudi Arabia Pavilion (Shanghai)


Figure 252: E4 - Expo 2010 Saudi Arabia Pavilion (Shanghai)


Figure 253: E4 - Expo 2010 Saudi Arabia Pavilion (Shanghai)

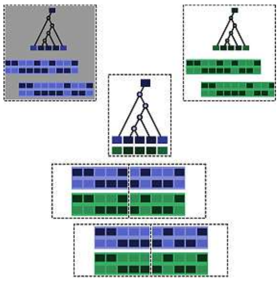

Figure 254: E4 - Expo 2010 Saudi Arabia Pavilion (Shanghai)

420 points of a possible maximum of 725; therefore 57% similarity.

Why is this comparison of interest?:

- The Syntax Trees are similar and orientationVerticalDown is in common
- Classification items from *Tilt* in combination with weak references are present
- Circular and elliptical shapes are present

focus: E3 – Kaleidoscope 1967



Page A

candidate: E4 - Saudi Arabia 2010

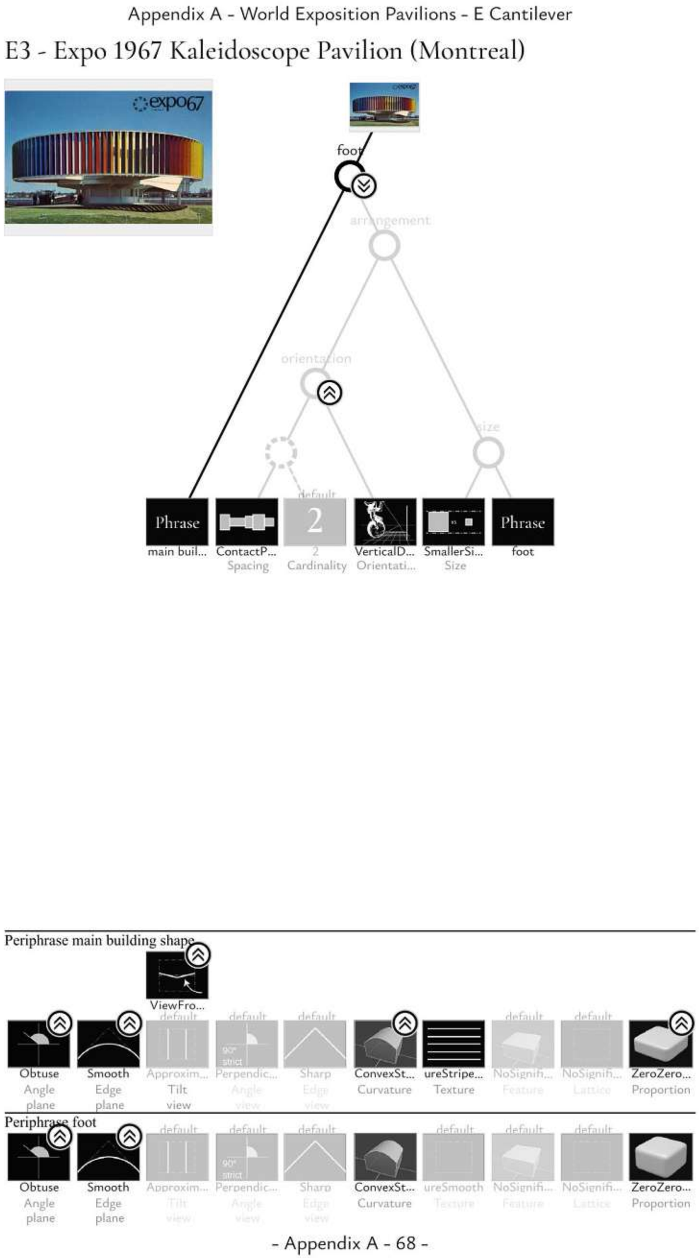
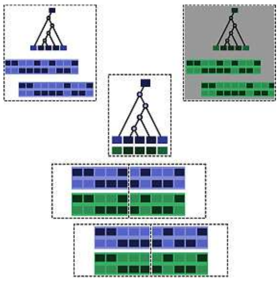


Table 1: Screenshot of Appendix page for E3 – Kaleidoscope 1967

focus: E3 – Kaleidoscope 1967



Page B

candidate: E4 - Saudi Arabia 2010

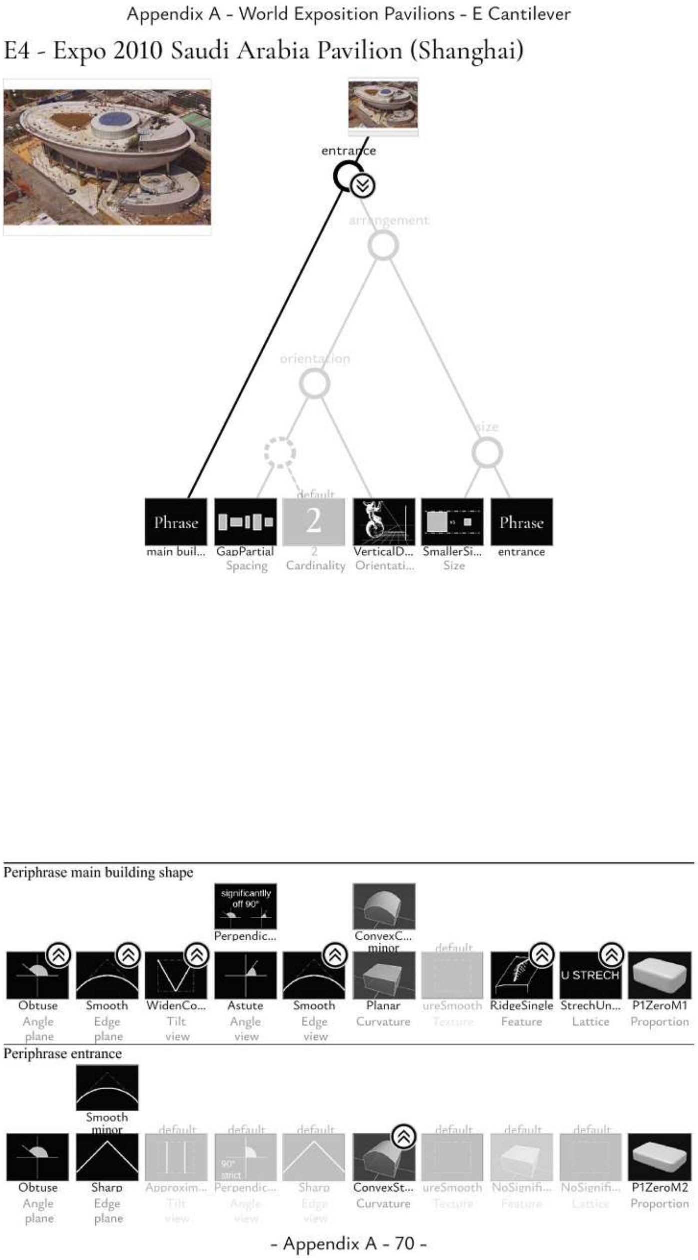
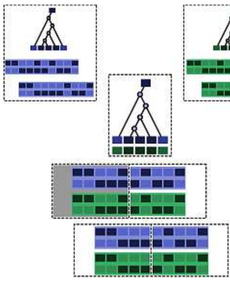


Table 2: Screenshot of Appendix page for E4 - Saudi Arabia 2010

focus: E3 – Kaleidoscope 1967



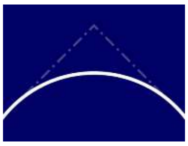
Page C

candidate: E4 - Saudi Arabia 2010

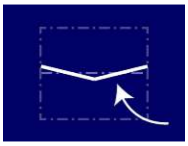
First Periphrase Σ 390

Angle plane	Edge plane	Tilt view	Angle view	Edge view
100	100	90		
significant vs. significant	significant vs. significant	significant vs. significant		
100 – 0% = 100	100 – 0% = 100	90 – 0% = 90		
direct match	direct match	hasVeryStrongLink		
100	100	100 – 10% = 90		

explicit significant angleObtuse



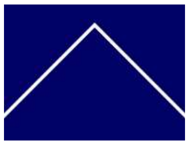
explicit significant edgeSmooth



explicit significant additional tiltViewFromBelow*

implicit tiltApproximatelyNone**

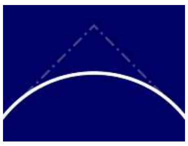
implicit anglePerpendicularStrict



implicit edgeSharp

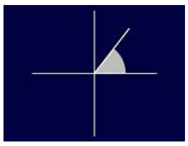
explicit anglePerpendicularOffSignificantly***

explicit significant angleObtuse

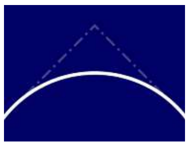


explicit significant edgeSmooth

explicit significant tiltWidenComplete



explicit angleAstute****



explicit significant edgeSmooth

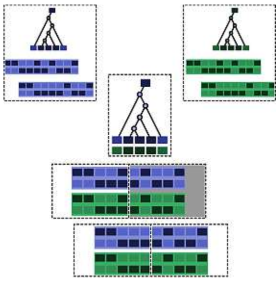
Note* & **: The Kaleidoscope has an implicit tiltApproximatelyNone which describe the vertical walls of the cylinder and it has an "additional" tiltViewFromBelow which describes the fact, that a person can see below the distinct building part.

Note *: The weak reference "tiltViewFromBelow hasVeryStrongLink tiltWidenComplete" works well and contributes 90 points.

Note *** & ****: The Saudi Arabia Pavilion has two explicit values for the Angle view slot, though none of it matches the implicit anglePerpendicularStrict from the Kaleidoscope, there zero points are calculated.

Table 3: Comparison of focus Periphrase "main building shape" and candidate Periphrase "main building shape", first 5 columns/slots

focus: E3 – Kaleidoscope 1967


Page D


candidate: E4 - Saudi Arabia 2010

First Periphrase Σ 390

Curvature | Texture | Feature | Lattice | Proportion

Curvature

40

significant vs. normal

50 – 20% = 40

hasNormalLink

100 – 50% = 50

Proportion

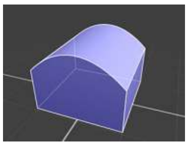
60

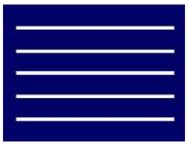
significant vs. normal

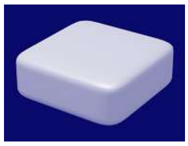
75 – 20% = 60

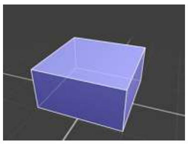
hasStrongLink

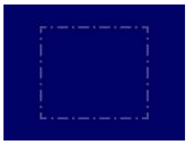
100 – 25% = 7

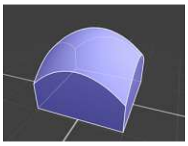

explicit significant
curvatureConvexStraight

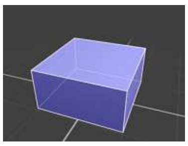

explicit
textureStripedRegular

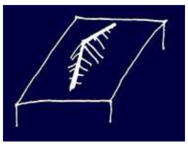

explicit significant
proportionZeroZeroM2


implicit
featureNoSignificant


implicit
latticeNoSignificant

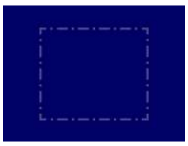

explicit
curvatureConvexConvex*


explicit minor
curvaturePlanar


explicit significant
featureRidgeSingle

explicit significant
latticeStrechUnproportional

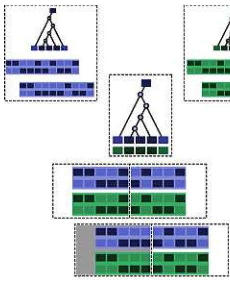

explicit
proportionP1ZeroM1


implicit
textureSmooth

Note *: candidate curvatureConvexConvex is selected to match against focus curvatureConvexStraight

Table 4: Comparison of focus Periphrase “main building shape” and candidate Periphrase “main building shape”, second 5 columns/slots

focus: E3 – Kaleidoscope 1967

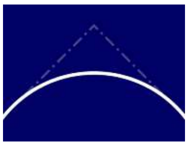

Page E


candidate: E4 - Saudi Arabia 2010

Second Periphrase Σ 415

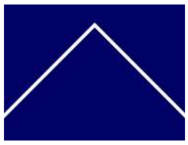
Angle plane	Edge plane	Tilt view	Angle view	Edge view
80	80	30	30	30
significant vs. normal	significant vs. significant	inferred vs. inferred	inferred vs. inferred	inferred vs. inferred
100 – 20% = 80	100 – 20% = 80	100 – 70% = 30	100 – 70% = 30	100 – 70% = 30
direct match	direct match	direct match	direct match	direct match
100	100	100	100	100

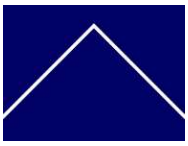

explicit significant angleObtuse


explicit significant edgeSmooth

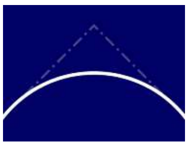

implicit tiltApproximatelyNone

implicit anglePerpendicularStrict

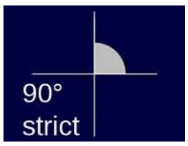

implicit edgeSharp


explicit minor edgeSharp


explicit angleObtuse


explicit edgeSmooth


implicit tiltApproximatelyNone



implicit anglePerpendicularStrict

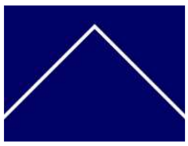
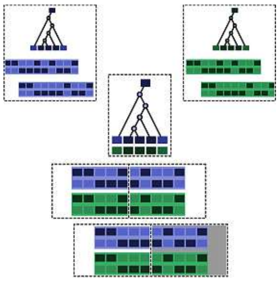

implicit edgeSharp

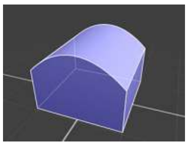
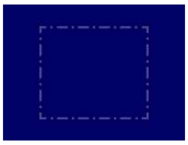
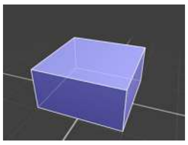
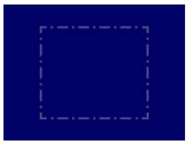
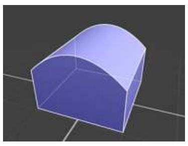
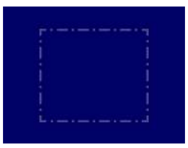
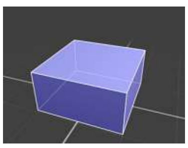
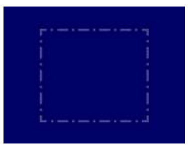
Table 5: Comparison of focus Periphrase "foot" and candidate Periphrase "entrance", first 5 columns/slots

focus: E3 – Kaleidoscope 1967


Page F


candidate: E4 - Saudi Arabia 2010

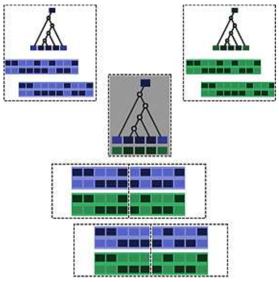
Second Periphrase Σ 415

Curvature	Texture	Feature	Lattice	Proportion
50	30	30	30	25
normal vs. significant*	inferred vs. inferred	inferred vs. inferred	inferred vs. inferred	normal vs. normal
100 – 50% = 50	100 – 70% = 30	100 – 70% = 30	100 – 70% = 30	50 – 50% = 25
direct match	direct match	direct match	direct match	hasNormalLink
100	100	100	100	100 – 50% = 5
 explicit curvatureConvexStraight				 explicit proportionZeroZeroM1
	 implicit textureSmooth	 implicit featureNoSignificant	 implicit latticeNoSignificant	
 explicit significant curvatureConvexStraight				 explicit proportionP1ZeroM2
	 implicit textureSmooth	 implicit featureNoSignificant	 implicit latticeNoSignificant	

Note *: The candidate curvatureConvexStraight is significant and the equal focus curvatureConvexStraight is normal. But according the Rule of Significance it does matter which value is the focus. This is done to prevent that any calculation exceeds the 100% match of the self-comparison. The value is clamped. We get the same penalty of 50% for "normal vs. significant" that we would get for "normal vs. normal" because the focus side defines the ceiling value. See chapter 9.7.3 for a table of the rules of significance values.

Table 6: Comparison of focus Periphrase "foot" and candidate Periphrase "entrance", second 5 columns/slots

focus: E3 – Kaleidoscope 1967



Page G

candidate: E4 - Saudi Arabia 2010

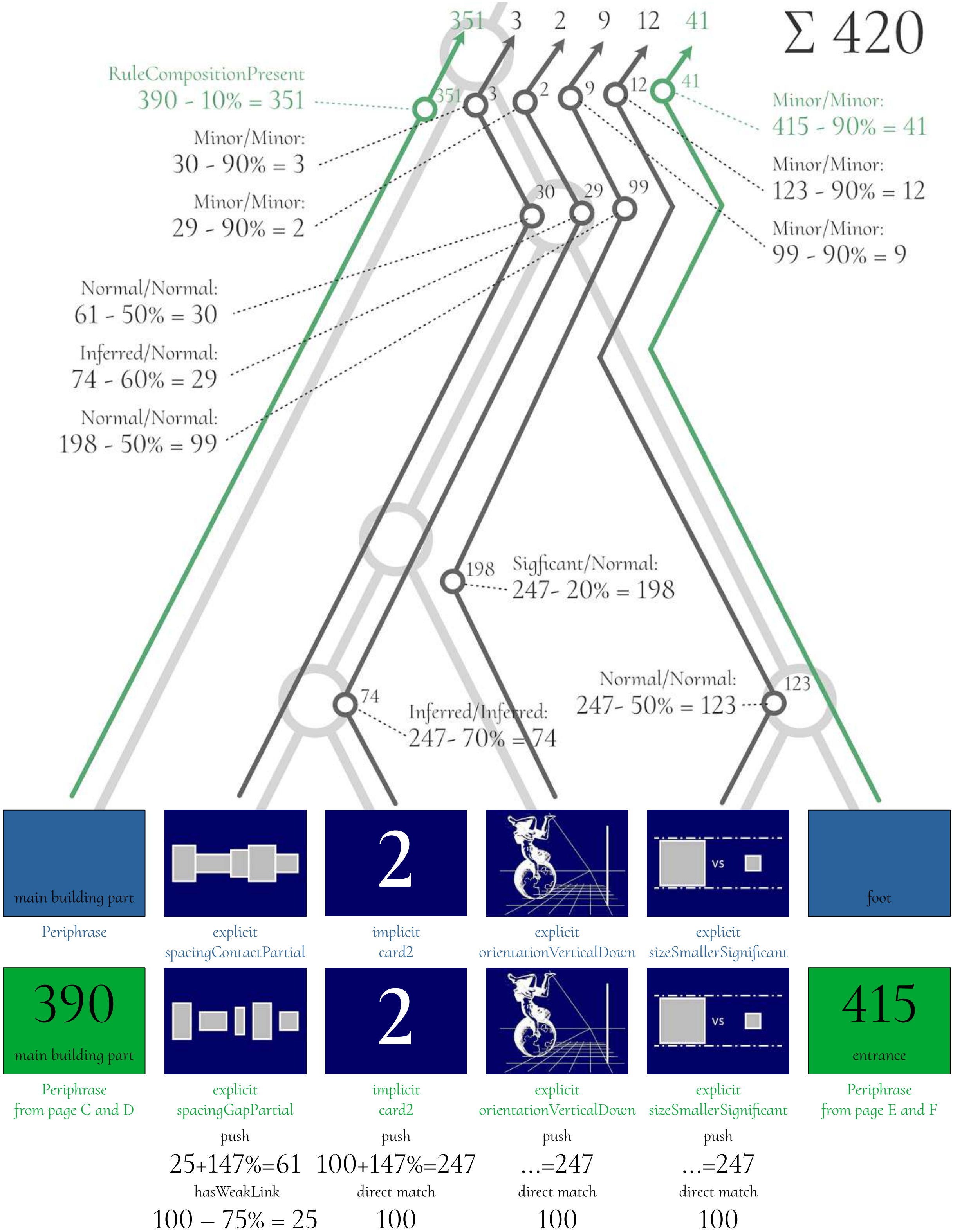


Table 7: Comparison of focus Syntax Tree and candidate Syntax Tree

10.2. Kaleidoscope and Quebec Pavilion

Focus Building: E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)

Figure 255: E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)

Figure 256: E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)

Figure 257: E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)

Candidate Building: E6 - Expo 1967 Quebec Region Pavilion (Montreal)

Figure 258: E6 - Expo 1967 Quebec Region Pavilion (Montreal)

Figure 259: E6 - Expo 1967 Quebec Region Pavilion (Montreal)

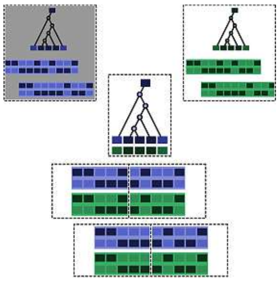
Figure 260: E6 - Expo 1967 Quebec Region Pavilion (Montreal)

333 points of a possible maximum of 725; therefore 45% similarity.

Why is this comparison of interest?:

- The Syntax Trees are similar and orientationVerticalDown is in common
- The Periphrase classification item tiltViewFromBelow is in common
- The Periphrase classification item proportionZeroZeroM2 is in common
- But the the remaining Periphrase items have little overlap, because a lot of fields in the candidate building default towards the perfect cube.

focus: E3 – Kaleidoscope 1967



Page A

candidate: E6 - Quebec Region 1967

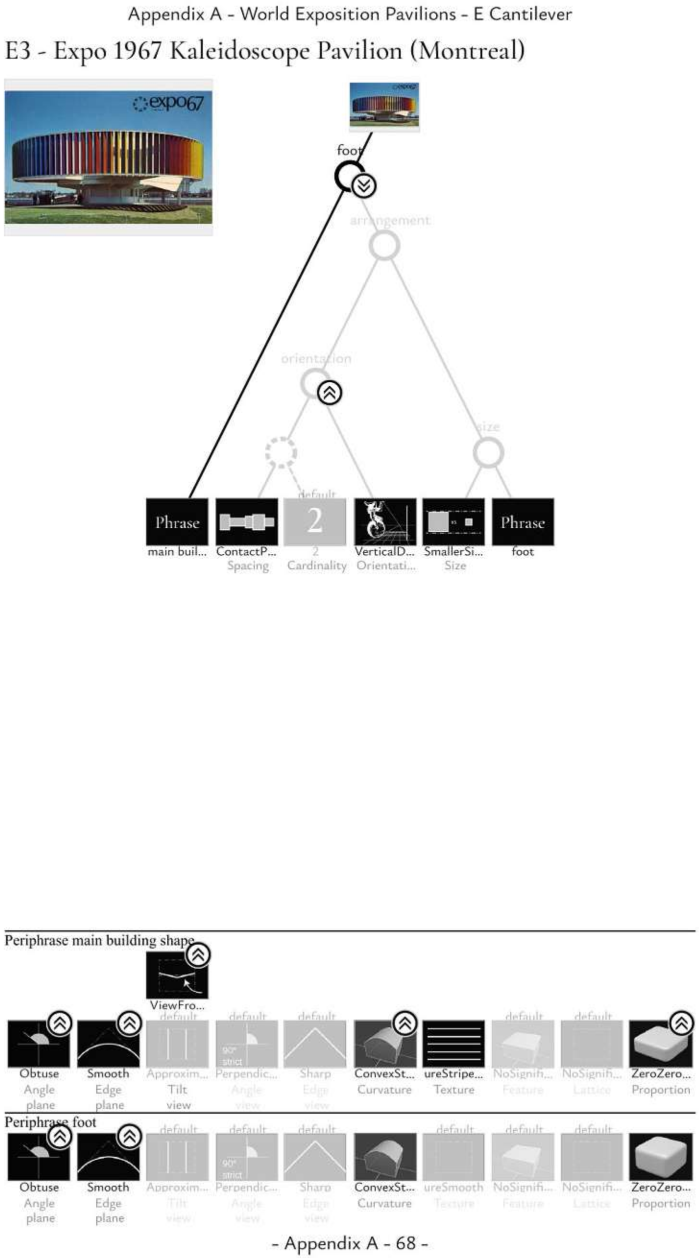
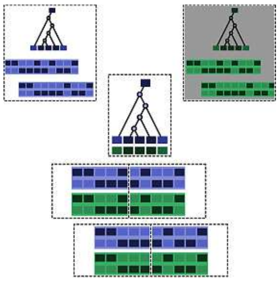


Table 8: Screenshot of Appendix page for E3 – Kaleidoscope 1967

focus: E3 – Kaleidoscope 1967



Page B

candidate: E6 - Quebec Region 1967

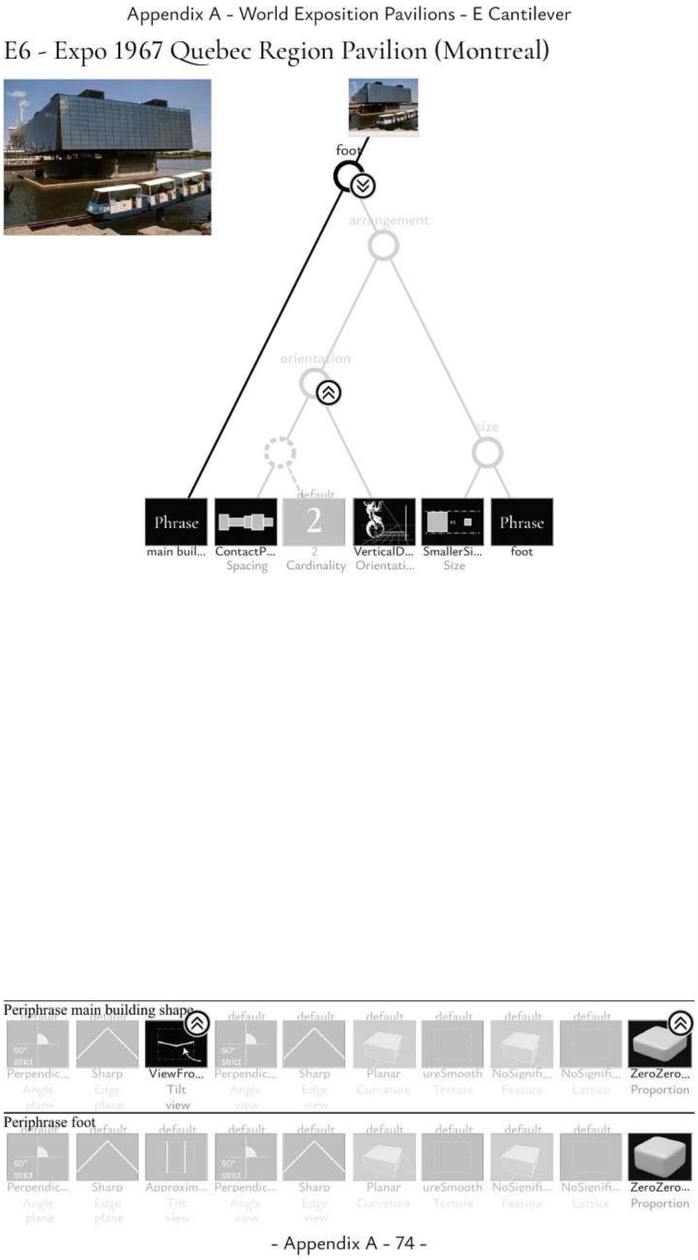
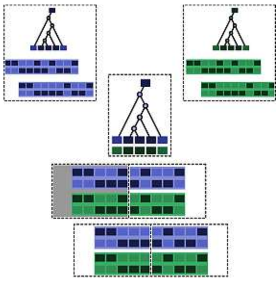


Table 9: Screenshot of Appendix page for E6 - Quebec Region 1967

focus: E3 – Kaleidoscope 1967


Page C

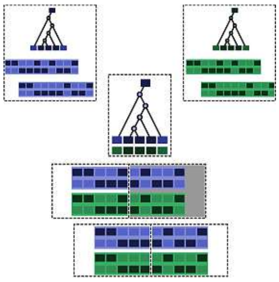

candidate: E6 - Quebec Region 1967

First Periphrase Σ 320

Angle plane	Edge plane	Tilt view	Angle view	Edge view
		100	30	30
		significant vs. significant	inferred vs. inferred	inferred vs. inferred
		100 – 0% = 100	100 – 70% = 30	100 – 70% = 30
		direct match	direct match	direct match
		100	100	100
explicit significant angleObtuse	explicit significant edgeSmooth	explicit significant additional tiltViewFromBelow*		
		implicit tiltApproximatelyNone**	implicit anglePerpendicularStrict	implicit edgeSharp
		explicit significant tiltViewFromBelow		
implicit anglePerpendicularStrict	implicit edgeSharp		implicit anglePerpendicularStrict	implicit edgeSharp

Table 10: Comparison of focus Periphrase "main building shape" and candidate Periphrase "main building shape", first 5 columns/slots

focus: E3 – Kaleidoscope 1967



Page D

candidate: E6 - Quebec Region 1967

First Periphrase Σ 320

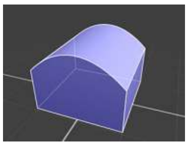
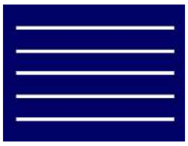
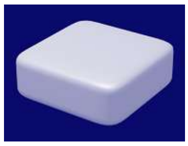
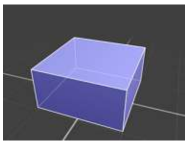
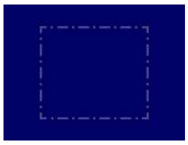
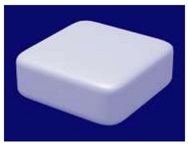
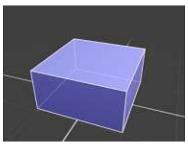
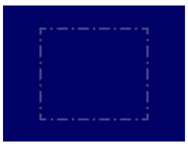
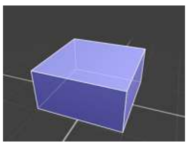
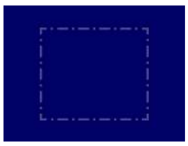
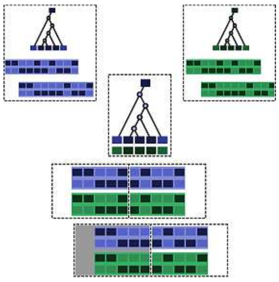
Curvature	Texture	Feature	Lattice	Proportion
		30	30	100
		inferred vs. inferred 100 – 70% = 30	inferred vs. inferred 100 – 70% = 30	significant vs. significant 100 – 0% = 100
		direct match 100	direct match 100	direct match 100
 explicit significant curvatureConvexStraight	 explicit textureStripedRegular			 explicit significant proportionZeroZeroM2
		 implicit featureNoSignificant	 implicit latticeNoSignificant	
				 explicit significant proportionZeroZeroM2
 implicit curvaturePlanar	 implicit textureSmooth	 implicit featureNoSignificant	 implicit latticeNoSignificant	

Table 11: Comparison of focus Periphrase "main building shape" and candidate Periphrase "main building shape", second 5 columns/slots

focus: E3 – Kaleidoscope 1967


Page E

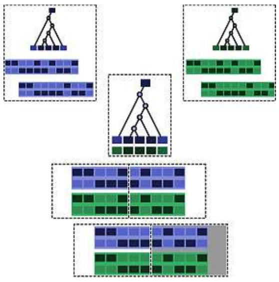

candidate: E6 - Quebec Region 1967

Second Periphrase Σ 230

Angle plane	Edge plane	Tilt view	Angle view	Edge view
		30 inferred vs. inferred 100 – 70% = 30 direct match 100	30 inferred vs. inferred 100 – 70% = 30 direct match 100	30 inferred vs. inferred 100 – 70% = 30 direct match 100
explicit significant angleObtuse	explicit significant edgeSmooth			
		implicit tiltApproximatelyNone	90° strict implicit anglePerpendicularStrict	implicit edgeSharp
90° strict implicit anglePerpendicularStrict	implicit edgeSharp	implicit tiltApproximatelyNone	90° strict implicit anglePerpendicularStrict	implicit edgeSharp

Table 12: Comparison of focus Periphrase "foot" and candidate Periphrase "foot", first 5 columns/slots

focus: E3 – Kaleidoscope 1967


Page F


candidate: E6 - Quebec Region 1967

Second Periphrase Σ 230

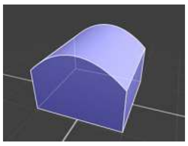
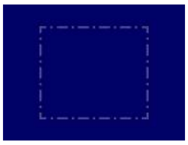
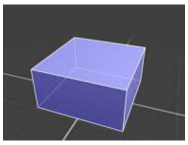
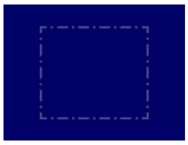
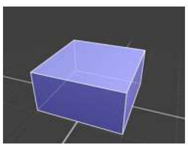
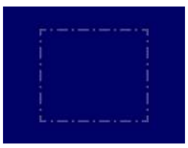
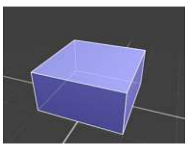
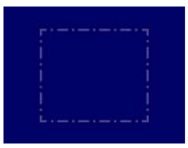
Curvature	Texture	Feature	Lattice	Proportion
	30	30	30	50
	inferred vs. inferred	inferred vs. inferred	inferred vs. inferred	normal vs. normal
	100 – 70% = 30	100 – 70% = 30	100 – 70% = 30	100 – 50% = 50
	direct match	direct match	direct match	direct match
	100	100	100	100
 explicit curvatureConvexStraight				 explicit proportionZeroZeroM1
	 implicit textureSmooth	 implicit featureNoSignificant	 implicit latticeNoSignificant	
				 explicit proportionZeroZeroM1
 implicit curvaturePlanar	 implicit textureSmooth	 implicit featureNoSignificant	 implicit latticeNoSignificant	

Table 13: Comparison of focus Periphrase “foot” and candidate Periphrase “foot”, second 5 columns/slots

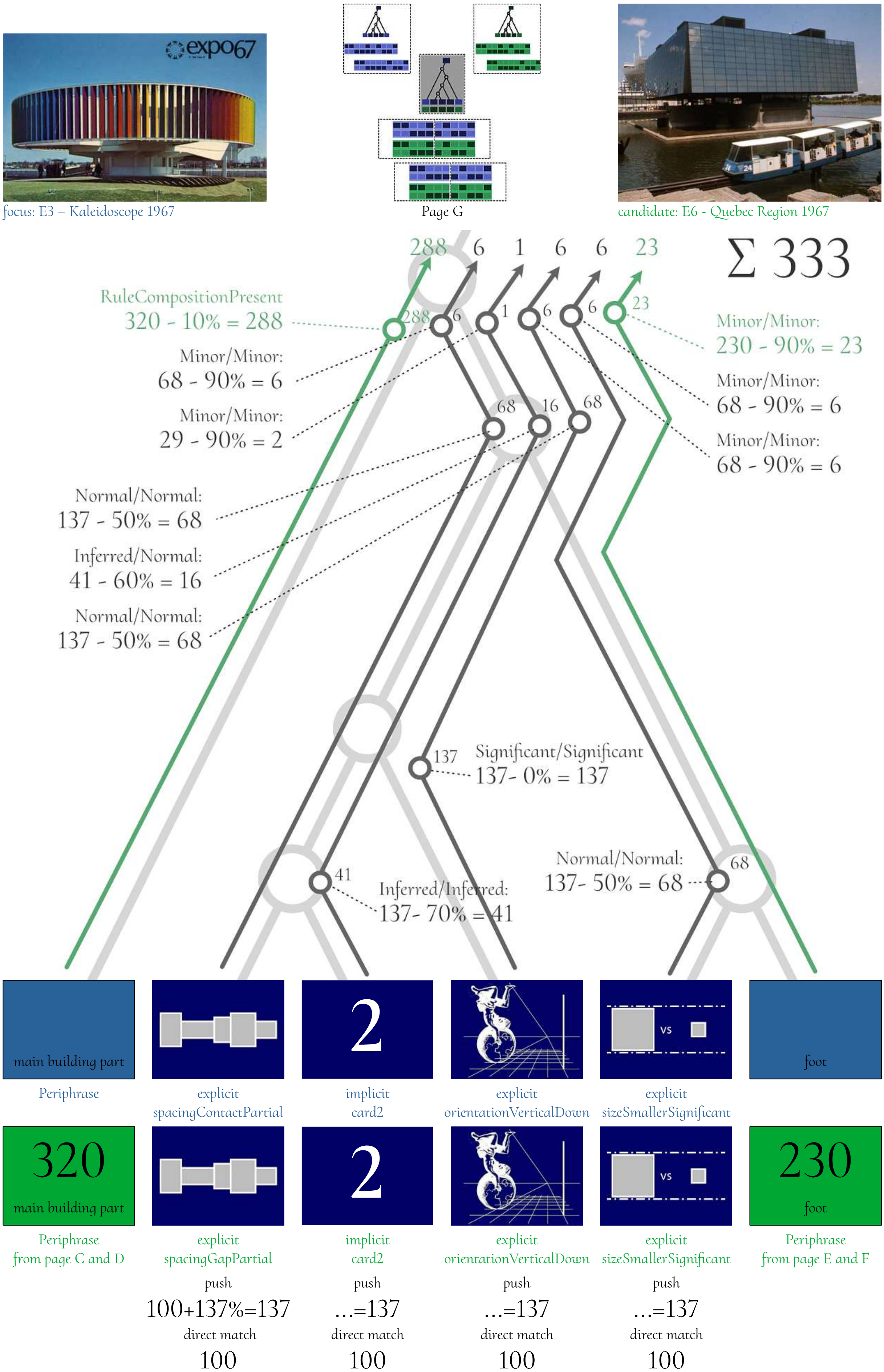


Table 14: Comparison of focus Syntax Tree and candidate Syntax Tree

10.3. Kaleidoscope and Canada Pavilion

Focus Building: E1 - Expo 1967 Canada Host-Pavilion (Montreal)

Figure 261: E1 - Expo 1967 Canada Host-Pavilion (Montreal)

Figure 262: E1 - Expo 1967 Canada Host-Pavilion (Montreal)

Figure 263: E1 - Expo 1967 Canada Host-Pavilion (Montreal)

Candidate Building: E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)

Figure 264: E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)

Figure 265: E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)

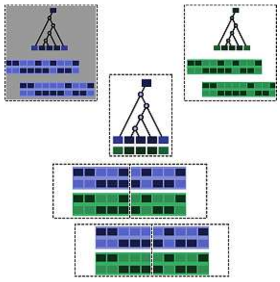
Figure 266: E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)

140 points of a possible maximum of 590; therefore 23% similarity.

Why is this comparison of interest?:

- The Kaleidoscope is here the candidate building rather then the focus building
- The E1 – Canada Host-Pavilion 1967 consist only of a single Periphrase and no Syntax Tree. Therefore there will be no Page E and Page F
- Tilt with tiltWidenComplete and tileViewFromBelow are present

focus: E1 – Canada Host-Pavilion 1967



Page A

candidate: E3 – Kaleidoscope 1967

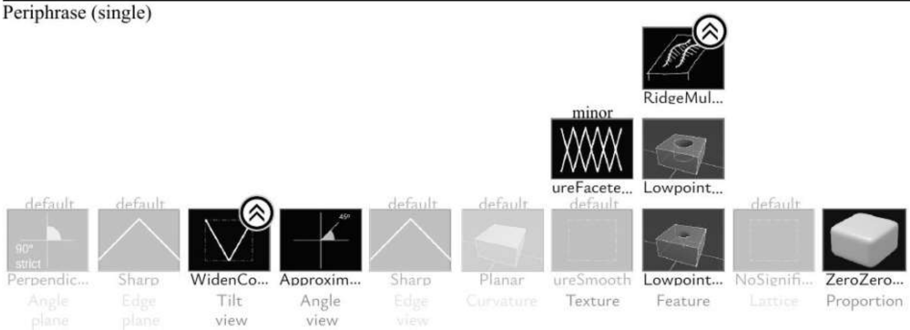
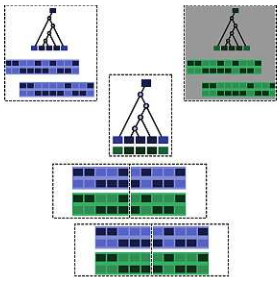


Table 15: Screenshot of Appendix page for E1 – Canada Host-Pavilion 1967

focus: E1 – Canada Host-Pavilion 1967



Page B

candidate: E3 – Kaleidoscope 1967

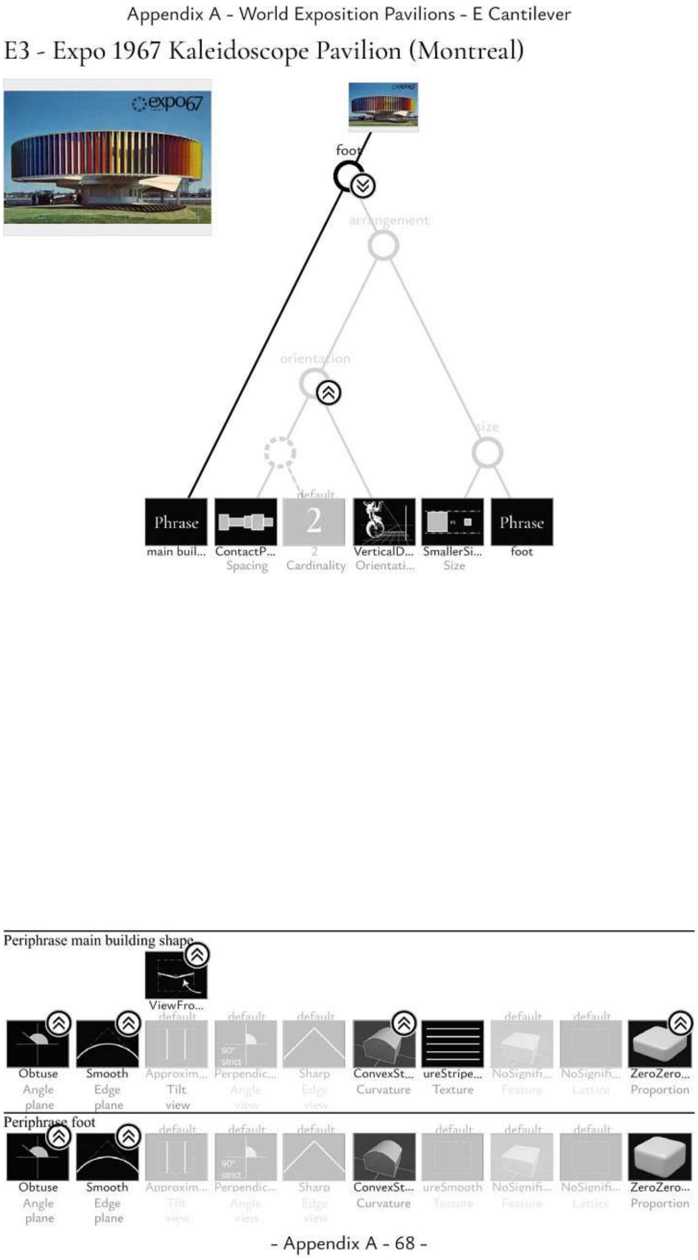
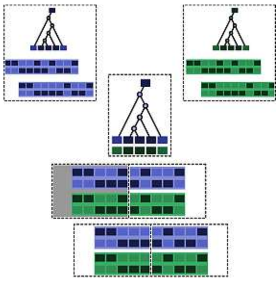


Table 16: Screenshot of Appendix page for E3 – Kaleidoscope 1967


focus: E1 – Canada Host-Pavilion 1967

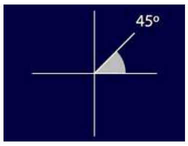

Page C

candidate: E3 – Kaleidoscope 1967

Single Periphrase Σ 187

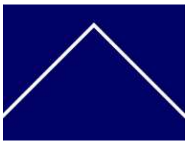
Angle plane	Edge plane	Tilt view	Angle view	Edge view
		90		30
		significant vs. significant		inferred vs. inferred
		90 – 0% = 100		100 – 70% = 30
		hasVeryStrongLink		direct match
		100 – 0% = 90		100

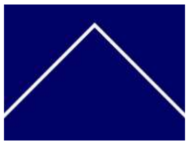

explicit significant
tiltWidenComplete



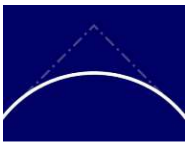
explicit
angleApproximately45

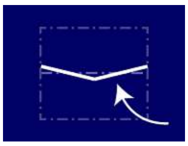
implicit
anglePerpendicularStrict


implicit
edgeSharp

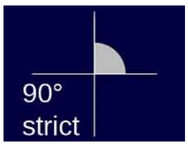

implicit
edgeSharp


explicit significant
angleObtuse


explicit significant
edgeSmooth


explicit significant additional
tiltViewFromBelow


implicit
tiltApproximatelyNone



implicit
anglePerpendicularStrict

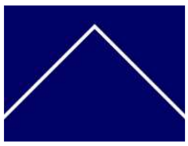
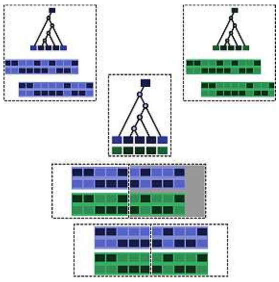

implicit
edgeSharp

Table 17: Comparison of focus single Periphrase and candidate Periphrase “main building shape”, first 5 columns/slots

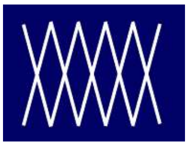
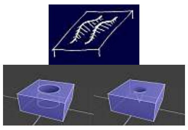
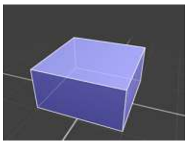
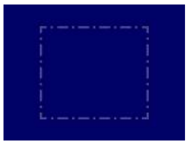
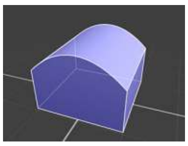
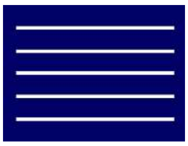
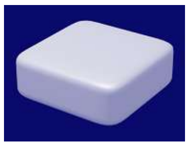
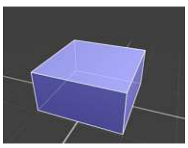
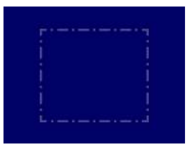
focus: E1 – Canada Host-Pavilion 1967



Page D

candidate: E3 – Kaleidoscope 1967

Single Periphrase Σ 187

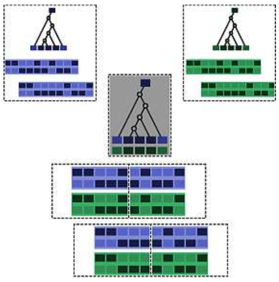
Curvature	Texture	Feature	Lattice	Proportion
			30	37
			inferred vs. inferred 100 – 70% = 30 direct match 100	normal vs. significant** 75 – 50% = 37 hasStrongLink 100 – 25% = 7
	 explicit minor textureFacetedRegular	 explicit significant featureRidgeMultiple*		 explicit proportionZeroZeroM1
 implicit curvaturePlanar			 implicit latticeNoSignificant	
 explicit significant curvatureConvexStraight	 explicit textureStripedRegular			 explicit significant proportionZeroZeroM2
		 implicit featureNoSignificant	 implicit latticeNoSignificant	

Note *: There are actually three explicit "feature" classification items. Non the less, no one does provide a match.

Note **: Please tee the explanation in Table 6 why the Rule of Significance applies here a penalty of 50%.

Table 18: Comparison of focus single Periphrase and candidate Periphrase "main building shape", second 5 columns/slots

focus: E1 – Canada Host-Pavilion 1967



Page G

candidate: E3 – Kaleidoscope 1967

No Syntax Tree Σ 140

RulePeriphrasePresent

187 – 25% = 140

single building part

Periphrase

187

main building part

Periphrase
from page C and D

Table 19: Comparison of (non existing) focus Syntax Tree and candidate Syntax Tree

10.4. Kaleidoscope and China Pavilion

After the previous extended comparison with multiple tables we will omit most of the tables and only discuss specific aspects.

Focus Building: E3 - Expo 1967 Kaleidoscope Pavilion (Montreal). Photos omitted for abbreviation. Please see previous comparisons.

Candidate Building: E2 - Expo 2010 China Host Pavilion (Shanghai)

Figure 267: Pedestrian View
E2 - Expo 2010 China Host Pavilion (Shanghai)

Figure 268: Aerial 1
E2 - Expo 2010 China Host Pavilion (Shanghai)

Figure 269: Aerial 2
E2 - Expo 2010 China Host Pavilion (Shanghai)

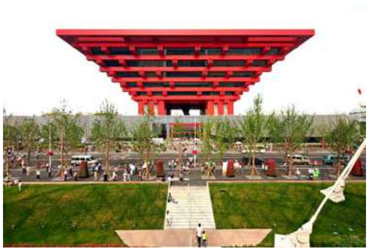


Figure 270: Pedestrian View 2
E2 - Expo 2010 China Host Pavilion (Shanghai)

Figure 271: Entrance View 1
E2 - Expo 2010 China Host Pavilion (Shanghai)

Figure 272: Entrance View 2
E2 - Expo 2010 China Host Pavilion (Shanghai)

261 points of a possible maximum of 725; therefore 36% similarity.

Why is this comparison of interest?:

- The China pavilion has a bigger Syntax Tree
- The China pavilion has a composition similar to the Kaleidoscope
- The “base” as well as as the “feet” are both located below the main building shape
- Interface rules are in action

E2 - Expo 2010 China Host Pavilion (Shanghai)

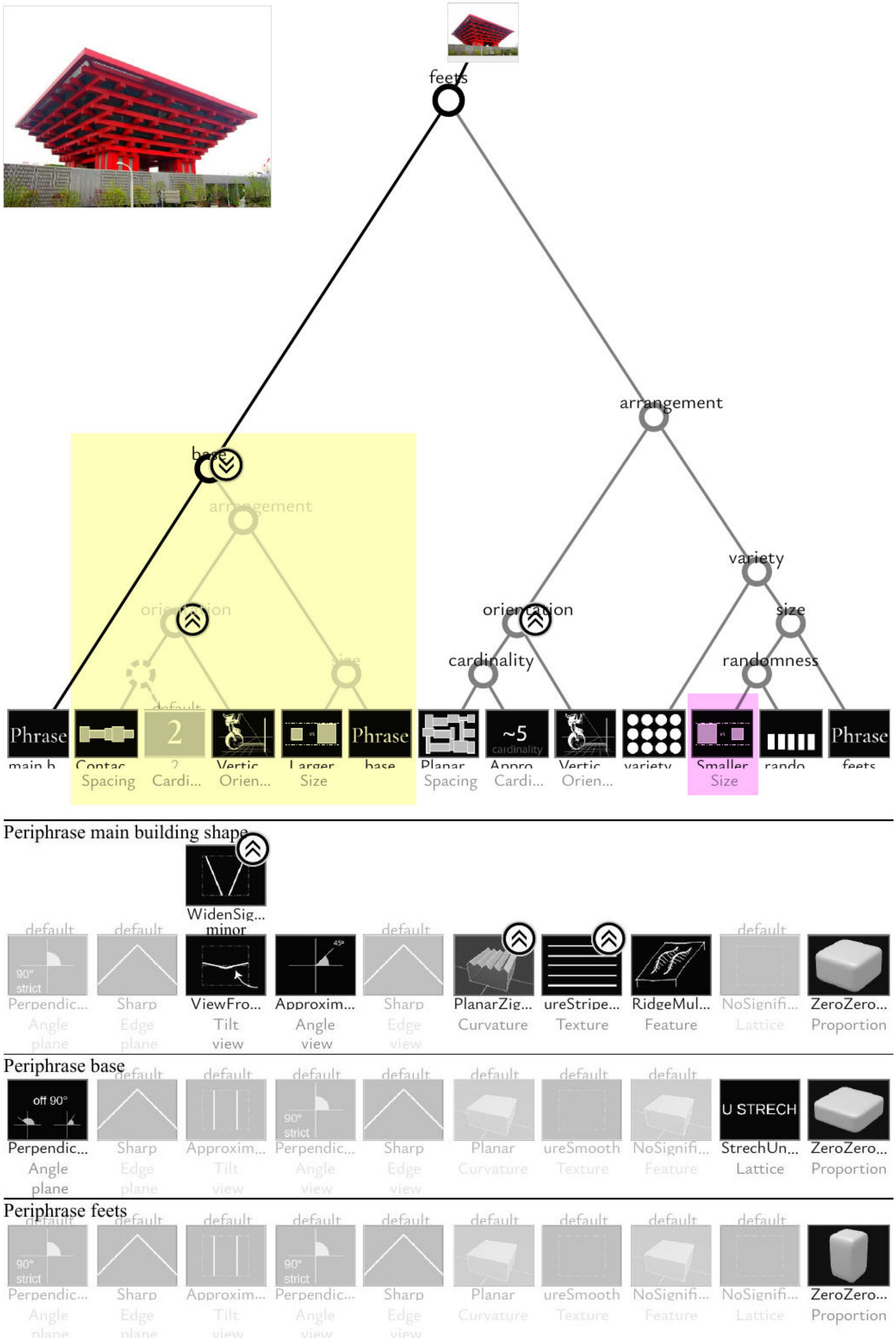


Figure 273: The Syntax Tree and all three Periphrases of the E2 – China Host-Pavilion 2010 .

- The yellow area emphasis the branch that is related to the big “base” distinct building part.
- The yellow area contains a “Relative Size” item of “larger”
  The magenta area contains a “Relative Size” item of “smaller”
- The Periphrase “base” contains an “Angle-Plane” item and a “Proportion” item which are closer to the Kaleidoscope “base”. The Periphrase “feet” of the China pavilion have one explicit item.

The interface rules between the Periphrases and the Syntax Tree are in effect. We describe the theory of *interface rules* in chapter 9.6 This comparison is an applied example of the logic at the interface. The software finds three Periphrases in the E2 – China Host-Pavilion 2010 and two Periphrases in E3 – Kaleidoscope 1967. It iterates over all combinations and picks the best performing pairs:

- Kaleidoscope Cylinder Periphrase as the best match for the Upside Down Pyramid Periphrase.
- Kaleidoscope Base Periphrase as the best match for the Feet Periphrase. Though the Kaleidoscope Base Periphrase has more overlap with the Base Periphrase. But the “dry run” exposes that the Base Syntax Tree is only of minor significance and therefore the Feet Syntax Tree is the better contributing one.

10.5. Hidden Simple

After the examples from the “cantilever” group, we compare two pavilions from the “hidden simple” group. The group got this internal name because there is a bigger group of about two dozens pavilions on the Expo 2010 that are *related*. They follow always the same pattern. There is a hall that contains the exhibition and it is fronted by a rectangular “identity tower” and a porch. The buildings are then *decorated* to give them some identity. The author assumes that this was a deliberate choice by the Chinese organizers of the World Exposition 2010 in Shanghai. These simple halls allowed several nations to have stand alone pavilions rather then just a section in a group pavilion. Especially smaller nations and less rich nations benefited from this pragmatic approach.

From a building shape point of view the members of the *hidden simple* group have very similar Syntax Trees. The identity is within the Periphrases. The group was also selected with the empirical part in mind. Would the participants be able to recognize the similarity despite of the decorative elements? Or might they even focus on the decorative elements because they make up the shape identity? Figures 274, 275 and 276 show three examples, but we will concentrate on the Angola and Algeria pavilions that we introduce on the next page.

Figure 274: C4 - Expo 2010 Monaco Pavilion (Shanghai)

Figure 275: C6 - Expo 2010 Croatia Pavilion (Shanghai)

Figure 276: C7 - Expo 2010 Sri Lanka Pavilion (Shanghai)

Focus Building: C1 - Expo 2010 Angola Pavilion (Shanghai)


Figure 277: C1 - Expo 2010 Angola Pavilion (Shanghai)


Figure 278: C1 - Expo 2010 Angola Pavilion (Shanghai)


Figure 279: C1 - Expo 2010 Angola Pavilion (Shanghai)

Candidate Building: C2 - Expo 2010 Algeria Pavilion (Shanghai)


Figure 280: C2 - Expo 2010 Algeria Pavilion (Shanghai)


Figure 281: C2 - Expo 2010 Algeria Pavilion (Shanghai)


Figure 282: C2 - Expo 2010 Algeria Pavilion (Shanghai)

507 points of a possible maximum of 601; therefore 84% similarity.

Why is this comparison of interest?:

- The Syntax Trees of the two shapes are identical
- The proportions are also similar. The building are also located next to each other
- The *decoration* is quite different

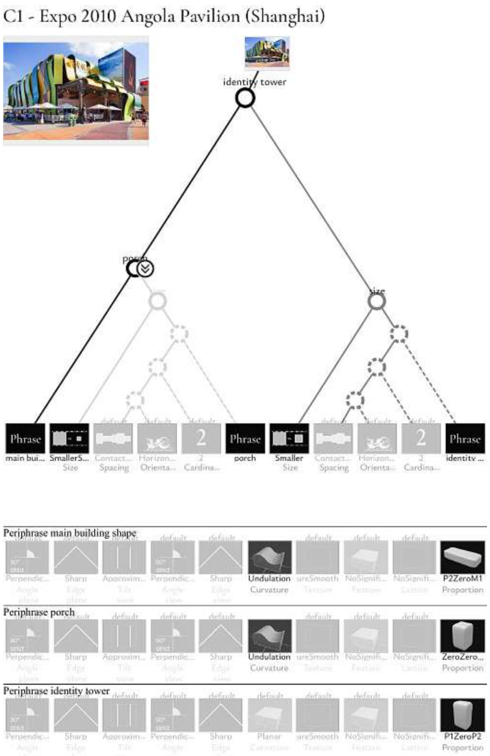


Figure 283: classification of focus
C1 - Expo 2010 Angola Pavilion (Shanghai)

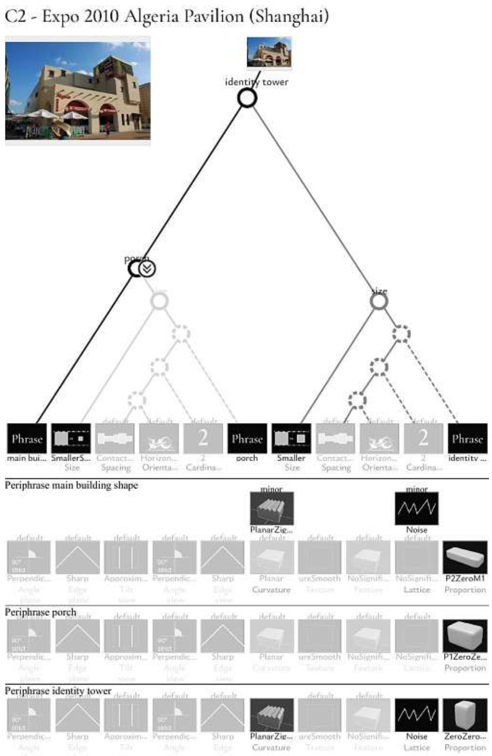
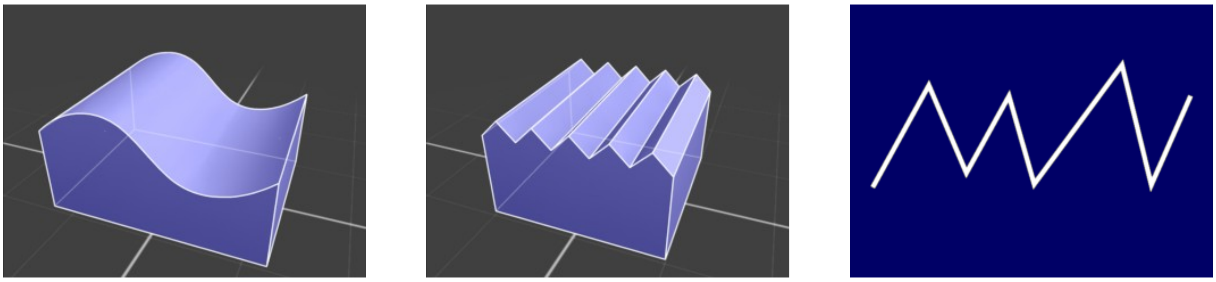


Figure 284: classification of candidate
C2 - Expo 2010 Algeria Pavilion (Shanghai)

We are skipping detailed comparison tables of the Periphrases and the Syntax Tree because it is obvious already from the high level Figure 283 and 284 that:

- The buildings have identical Syntax Trees
- Different to the Kaleidoscope, the Syntax Tree for the identity tower is not of minor significance, but rather at default significance. Therefore we expect higher values to make it to the top from this branch then seen before.
- The buildings use a lot of default values (light grey icons). This is due to the fact, that the system defaults to an implicit perfect cube if no explicit classification is present in a Periphrase. To describe a rectangular block, it is sufficient to just define the proportions.
- This also works for the composition because the system defaults to two distinct building parts that are located next to each other without perfectly covering the whole surface where they meet. This is the arrangement that is needed here.
- They differ in the explicit classification items for the Curvature slot. The Angola pavilion additionally has a classification item of latticeNoise in the Lattice slot.



a: curvatureUndulation b: curvaturePlanarZigZag c: curvatureConcaveStraight

Figure 285: Periphrase classification items used in C1 - Angola Pavilion 2010 (a) and C2 - Algeria Pavilion 2010 (b, c)

The final score value of 507 at the root of the syntax tree add up like this (rounded):

- 290 - Periphrase main building
- 131 - Periphrase Identity tower
- 47 = 26 + 13 + 3.5 + 3.5 Syntax Tree items in the identity tower branch
- 29 Periphrase porch
- 10 = 5 + 3 + 1 + 1 Syntax tree items in the porch branch

We can observe that Periphrases contribute ~89% and the Syntax Tree items ~11%. For the first Kaleidoscope example (10.1) the distribution is ~94% from Periphrases and ~6% from the Syntax Tree items. Therefore the Syntax Tree plays a more important role in this example. Roughly at a factor of two.

When we perform a mind experiment where we would just do keyword tagging: It would most likely overemphasise the differences in Curvature and Lattice from Figure 285. In contrast, we can see some benefits delivered by the proposed classification system of this thesis. Also the classification data in Figures 283 and 284 looks vast, only the dark items are the explicitly proved by a person. The rest is added implicitly by the software.

11. Empirical Data Gathering

In the previous chapters we introduced a theory that consist of a novel way to do building shape classification. We also have a software implementation[228] of significant parts of the theory. To verify that the theory and its implementation are producing useful similarity values there is a test against empirical data that serves as a reference. This chapter documents the data gathering sessions. Chapter 12 will compare the calculated data with the empirical data. The empirical data set was produced deliberately for this thesis and had 52 participants in multiple data gathering sessions. The participants produced ~18000 data points with rating decisions.[229]

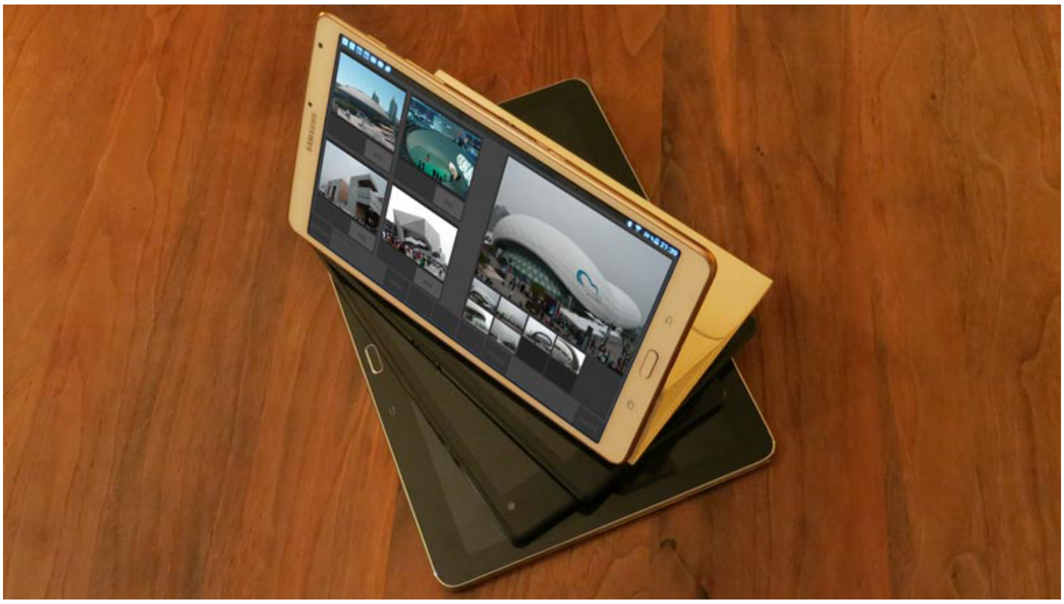


Figure 286: Tablet devices used in the empirical data gathering sessions.

11.1. Experiment Setup / Use of Photographs

We will look at 80 World Exposition pavilions. We discussed in chapter 6.3.1 that these kind of buildings are a good group because they have many aspects in common.

The participants looked at photographs of the World Exposition pavilions on a computer screen (Figure 286). We discussed in chapter 7.2 in the section about "Gesture becomes aerial" that the use of photographs should be acceptable. In the context of architecture we can further support this with some empirical work from the research

228 See Appendix D (19.4) and Appendix E (19.5)

229 The participant actually produced more empirical data, but we will only use from each of the 52 participants the first 88 plates, with 4 comparison each, minus irregularities. (52 x 88 x 4 = 18304)

group Sonderforschungsbereich 64 (SFB64). These researcher are related to the IL 22 work of chapter 5.4.2. A German language footnote provides some details.[230]

We can further elaborate on this from a Vision research point of view. The use of simple computer monitors looses the following benefits:

- Binocular disparity is one of the most, if not the most effective depth cue (Pizlo, 2008, p. 136).*et al.*, 2014, p. 155).
- Computer monitors can not produce "gradients of accommodative blur" (Todd and Norman, 2003, p. 2).
- The use of locomotion is missing (Lee *et al.*, 2012).
- Motion parallax
- Accommodation
- Vergence cues

Therefore Vision researchers argue about the usefulness of computer monitors and photographs when it comes to empirical experiments in laboratories that focus on features of visual perception and shape recognition. Still the use case is different for research topics outside of a laboratory. The *context* of the object becomes part of the perception. Vision researchers also argue about the use of *context* and photography in empirical setups.[231] They generally agree that it is acceptable to do so, when the experiments is not about isolation of a single perception feature like a "shade depth cue" (Pizlo *et al.*, 2014), (Lee *et al.*, 2012). The relative slow *mental rotation* which we are capable of helps together wit the *context*. Context might include: Colour, texture, shadow, horizon lines, inferred direction of gravity, and more then one similar reference object.

230 The following is a quote from (Deinhammer, 2016). The quote itself references page 76 and 77 of: Dirlewanger, H., Geisler, E. and Magnagno-Lampugnani, V. (1980) Zur Gestaltung weit gespannter Flächentragwerke - Entwerfen unter Berücksichtigung von Nutzervorstellungen. Stuttgart: Universität Stuttgart.

> I.5.2.3 Verwendung fotografischer Abbildungen von Gebäuden – Inwieweit können die Beurteilungen von Abbildungen Gültigkeit für die dreidimensionale Realität erlangen? Ist es wirklich möglich mit Hilfe von Abbildungen und Modellfotografien Aussagen über die Erlebnisqualität zu erlangen? Die Forschergruppe überprüfte diesen Sachverhalt indem sie drei Gebäude anhand von Modellfotos und Fotomontagen beurteilen ließ. Die Urteile verglich sie mit den Nutzerurteilen über das reale Gebäude, wobei die realen Bauwerke unwesentlich besser abschnitten als die auf den Abbildungen. Deshalb sehen es die Mitglieder des SFB64 als zulässig Urteile mittels Bildbetrachtung als wissenschaftlich seriös anzusehen.

231 See also:
Kanade, T. (1981). Recovery of the three-dimensional shape of an object from a single view. Artificial Intelligence, 17, 409–460.
Li, Y., Pizlo, Z., & Steinman, R.M. (2009). A computational model that recovers the 3D shape of an object from a single 2D retinal representation. Vision Research, 49, 979–991.

When we investigate things at the scale of World Exposition pavilions then the additional context objects are typically:

- Horizon lines.
- The shadow cast by the pavilion.
- Familiar objects within the pavilion, like a door.
- Familiar objects like humans or vehicles.
- Other buildings which might also have familiar elements like lines of windows.
- Eye level height based on other people in photograph taken from a pedestrian point of view.
- Inferred direction of gravity, from typically vertical reference objects like pedestrians, street lamps, street signs, vehicles.
- Inferred ground plane, from streets with markers, water, or pedestrian walks.
- When there are multiple similar reference objects in the photograph like pedestrian we can infer additional information due to the perspective foreshortening.

11.2. Transcript of Verbal Introduction

This subchapter is a transcript of the verbal introductions. The writing style is different to the rest of this thesis. It uses the first person perspective. This is due to the fact that all data gatherings have been supervised by the author of this thesis.

The main purpose of this chapter is a documentation of the verbal introduction which I gave in slight variations to the participants of the empirical data gathering in 13 sessions. The introduction have been given in German language.[232]

11.2.1. Thirteen Data Gathering Sessions

I conduced 13 data gathering sessions with up to five participants that were granted a compensation of 25 Euros for participating approximately 2 hours. The sessions took place at the TU Wien (Vienna University of Technology) in a dedicated seminar room.

The first eight session took place between 15th of Jan 2015 and 3rd of Feb 2015, which is the end of the semester. All but one session started at 17:00 h. One session started at 14:30 h. The participants in January were found by sending out an email newsletter to students that were known to the institute and by posting an advertisement at a popular online forum run by the student association.

Additional five sessions took place between 20th and 29th of April 2015, which is in the middle of the semester. Two sessions started at 14:30 h, one at 16:30 h and two at 17:00 h. The participants in April were found by traditional means like pinned up paper advertisements in well frequented university spots and verbal announcements at the end of a lecture by a colleague.

52 people participated:

- 23 of them had an architecture education background
- 14 had a civil engineering education background
- 15 had a different background

11.2.2. Welcome and First Instruction Part

The introduction was verbal and was held in the first 15 minutes of each data gathering session in front of two to five participants with a projector. The structure of the introduction followed the pattern:

232 Two international students also participated. I asked them to come 15 minutes earlier and gave them the introduction in English, before their peers arrived for the German language introduction.

- Research context – Why did I invited the participants?
- Content – What will be shown and what is the focus?
- Technology – How to use the software?
- Procedure – How long will it take?

There was also one additional instruction 15 minutes before the end. This will be documented as the *summary part* further below.

11.2.3. Research Context

The two up to five participants were welcomed and I started the introduction session by standing next to the computer screen projected on a white board. The projector showed the first screen of the software application but was not referenced in this first minutes.

I started by stating that this is part of my doctoral research at the institute of Interdisciplinary Construction Process Management at TU Wien.

To start with I explained that it is possible to type in geometrical words into the Google Image Search Engine like “architecture pyramid” and retrieve quite useable visual results like the Pyramids of Gizeh and most likely the glass pyramid in the Louvre in Paris and maybe even the pyramid in Vösendorf. This still works to some extend for terms like “architecture sphere”. But when one is interested in more complex building shapes one can’t type in some clear text keywords and retrieve many useful results any more.

Above statement was used to connect my research to an activity that many people perform in their day to day work: The problem of finding good results in retrieval systems like search engines.

I stated that the outcome of my doctoral thesis will not be some highly intelligent software product that can cater all needs. Such user centric software is something that future research could produce. Though I contribute some foundational work that might help in such a smart software.

Above statement was used to set the expectation correct.

I stated that I can write computer software and do this for a living. It’s possible for a software developer to write a computer program that does exactly what the author wants it to do. To be more scientific, I need a more neutral body of data to verify my approach. This neutral data is the statistical mean data that will be gathered by sessions like this one. And that’s the reason why I invited people to these sessions.

Above statement was motivated by feedback from a colleague who helped to set up the sessions. He used a quote from literature to question if software written by the same person that uses the software might not be objective. By emphasising the value of statistical means from many people I tried to show the participants that they provide important data.

I clarified that the gathering of the data is at the centre of the session. This is not a sociology experiment “where one person will give electric shocks to another” and it does not matter if one takes some of the provide water, peanuts or cookies.

Above statement was used to relax participants. Maybe some peoples expected this kind of experiment and would focus on their social behaviour and interaction with their peers rather than concentrating on the simple data gathering task.

I did not formulate my research hypothesis to the audience. I did not disclose why and how I grouped the data before the participants finished with the whole data gathering session.

11.2.4. Content Instructions

The projector showed a first screen of the software as in Figure 287. We will refer to these kind of screens as *plates* in the rest of this chapter. I explained that this first plate is just for demo and training purpose and the data will not be used.

I stated that I’m only interested in *building shape* defined as the outer visible shape of the buildings and that all other aspects should be ignored as far as possible.

The following aspects should be ignored:

- Architectural style – and historic context
- Structural system
- Material – It does not matter if something is made out of glass, concrete or textile.
- Colour – I hinted that some buildings are very colourful but asked to ignore this. I tried to convert photos to black and white but this made them hard to read and hard to distinguish between neighbouring buildings.
- Application – I explained that the approach how to make application/function ignorable works by haven the same application/function for all buildings that will be shown. They are all World Exposition pavilions standing next to other pavilions and their function is to enclose an exhibition curated by a nation, organisation or corporation. The pavilions try to attract pedestrians to come inside and visit the exhibition. Most of the pavilions are temporary and last only for half a year.

I asked the groups if they are familiar with World Expositions. If someone negated I tried to explain in a few very short sentences what these exhibitions are about, how often they occur and who is participating.

I used the five buildings on the demo plate to point out different aspects (see Figure 287). The five buildings on the demo plate were always the same and they were also World Exposition pavilions which did not make it into the final selection. In the rest of this subchapter we will rather use screenshots of plates that contain our canonical example: the Kaleidoscope.

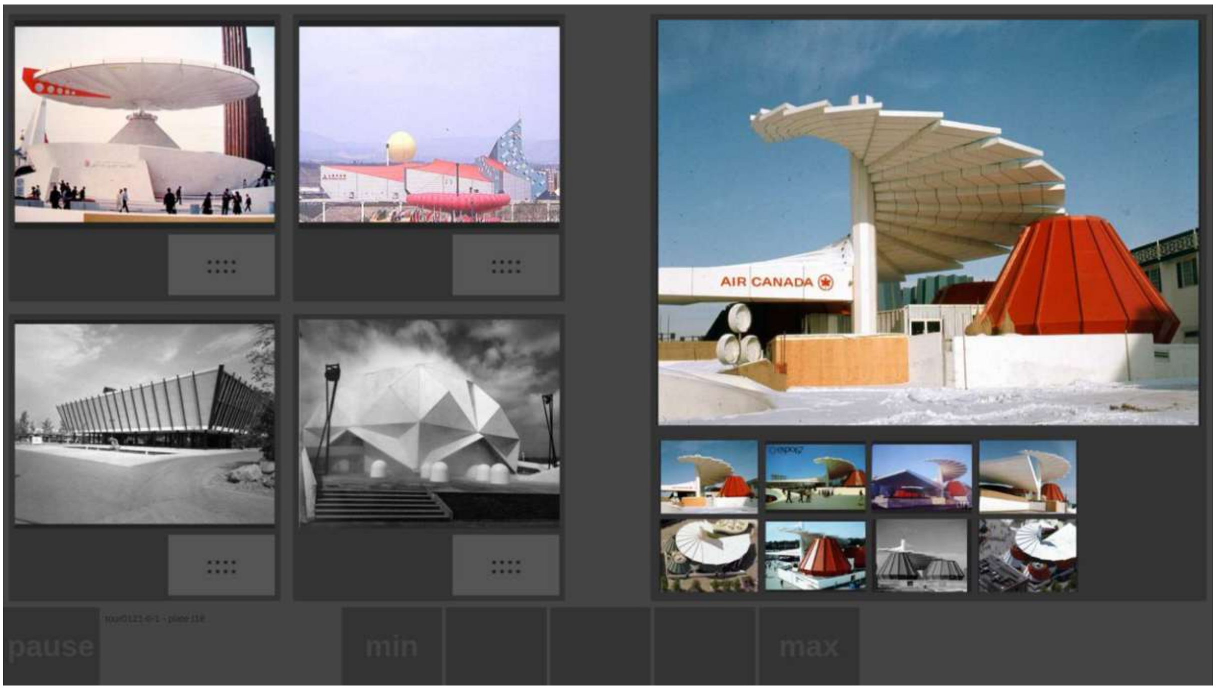


Figure 287: Demo plate used during the introduction. The Air Canada Pavilion as the focus on the right. Wacoal Riccar, Mitsubishi, Australia and Pepsi Pavilion on the left comparison side.
left: Expo 1970 Wacoal Riccar Corporate Pavilion (Osaka)
left: Expo 1970 Mitsubishi Corporate Pavilion (Osaka)
left: Expo 1967 Australia Pavilion (Montreal)
left: Expo 1970 Pepsi Corporate Pavilion (Osaka)
right: Expo 1967 Air Canada Corporate Pavilion (Montreal)

11.2.5. Technology

After the content instructions I switched to the technology instructions which I demonstrated at the demo plate.

I hinted to the participants that they can now use the provided Android tablets and they are free to try out the interaction on the touch screen and get familiar with the user interface. I advised not to press the “next” button, because this would be the start signal for the real work.

I explained that to the right there is a *focus building* and to the left are four *comparison buildings*. The task of the participants was to rate the *building shape similarity* between the one focus building with each of the comparison buildings.

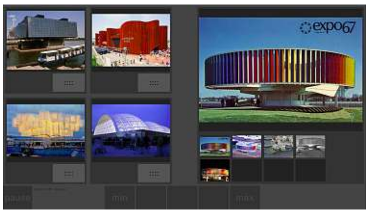


Figure 288: User Step 01
Some typical user story interactions shown with a plate with the focus building E3 - The Kaleidoscope. It serves as a canonical example.

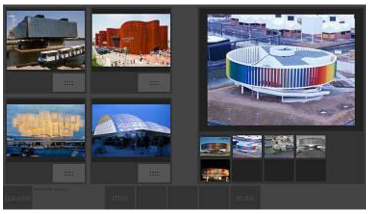


Figure 289: User Step 02
The user can see further photographs for the focus building on the right. By clicking on the thumbnails below the main photo.

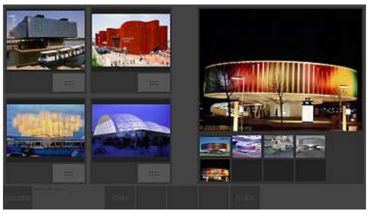


Figure 290: User Step 03
A third photograph

I explained the usability of the thumbnail and the zoom feature (see Figures 288, 289, 290, 291, 292 and 293). I also explained that the participants can use the pinch-zoom-gesture with their fingers to zoom the entire screen like they might be used to with photos on a smartphone.

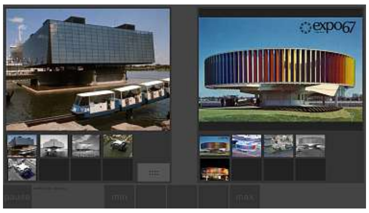


Figure 291: User Step 04
It is also possible to enlarge each of the four comparison buildings on the left.

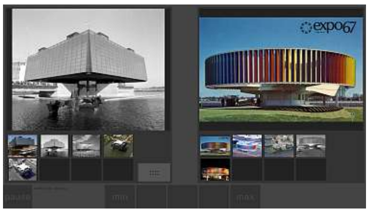


Figure 292: User Step 05
Additional photographs are also available for the comparison building.

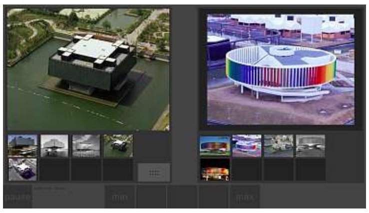


Figure 293: User Step 06
User can flip through the photographs on both side until they feel comfortable to make a rating.

Then I moved ahead to explain the rating part: "But how do you state your decision / rating?". Each plate had five boxes at the bottom. I will call them *rating boxes* in this text. The rating boxes had no numbers but rather the most left rating box was labelled "min" and the most right rating box was labelled "max" (see Figure 300). I explained that *min* stands for "minimal similarity of the building shapes" and *max* stands for "maximum similarity of the buildings shapes". I explained how users can drag and drop the comparison building into rating boxes and that this is the act of rating (see Figures 294, 295, 296, 297, 298 and 299).

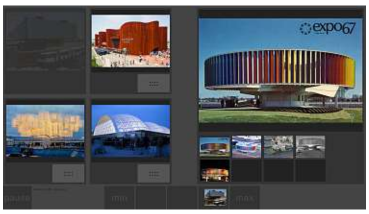


Figure 294: User Step 07
The user performed the first rating by dragging the upper right comparison building into the bottom row into the forth box.

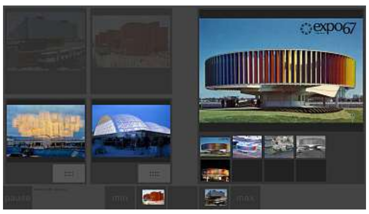


Figure 295: User Step 08
An additional rating into the second box. The rated buildings are greyed out, so the user can see the progress.

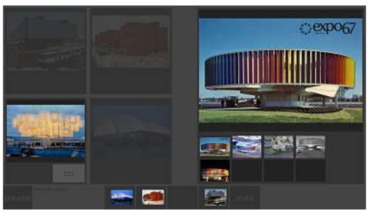


Figure 296: User Step 09
An additional rating into the first box. This is the "min" box.

I added the following statement in all session:

Please be generous with the *max* value. There are no two completely similar buildings and if you use the full range of rating boxes in your rating decisions it makes the data better for analysis with statistical tools. But of course please don't overdo it and don't put everything that is slightly related into the *max* rating box.

This statement was motivated by review of the behaviour of my beta testers which hardly used the max value and seldom the next highest value as well. The better the data is spread the easier it is to detect trends. In the data crunching after the data gathering sessions it would have been possible to *normalise* the data per user if necessary. No normalisation based on per user data was utilised. Observations during the sessions by me walking around the table hinted that this worked better then with the beta testers.

I explained that there are five rating boxes that represent ratings but only four buildings to drag and drop into. Therefore there will be gaps and that's OK. I stated that I'm even interested if there are wider gaps and that they can also drop two or even more buildings into the same rating box if their decision is that they should have the same value. I explained that the gaps and groups represent information how the group of the four buildings interrelate in the context of the one focus building.


Figure 297: User Step 10
The user investigates the last comparison building on the left.


Figure 298: User Step 11
The user also changes the photograph of the focus building on the right

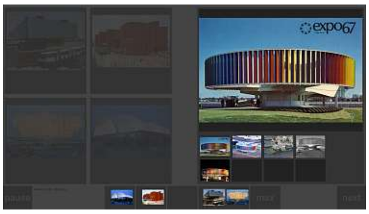


Figure 299: User Step 12
The user settles for a rating into the forth box. All buildings are rated and the "next" button appears.

I explained that the participants can change their mind and regroup the buildings which are already in the rating boxes and demonstrated this on the plate with the demo data. I explained and demonstrated that the users can drag a buildings out of the rating box back into the viewer area and have a second look at the building and drag it back into a rating box.

After all four comparisons are placed in rating boxes a button labelled "next" will appear. It is the pressing of this *next* button that makes the rating decision of a participant final. After that interaction users will be presented the next plate with a different set of buildings. I mentioned that there are 80 different buildings and that they will reappear over and over again, and that one can assume that one is slower at the beginning and will speed up in the process.

Figure 300: Close up of the bottom row after all ratings are done. Two buildings are together in the forth rating box.

I demonstrated a typical and complete use of one plate with the help of the demo plate.

At this point I emphasised that the usability of the data gathering software is not the subject of the work but rather the data and the rating decisions. I explained that it is okay to ask me questions about the user interface during the sessions. A few participants took the opportunity asked simple user interface questions in the very first minutes.

I explained that there is a button labelled “pause”. It is okay for participants to press it and make a break when they are distracted by something like a phone call or text message. After the distraction they can simply press the *pause* button again and continue. I did not disclose to the participants that I will drop any data that comes from screens that were paused. A few participants used the pause button as anticipated.

I answered any usability questions or repeated parts if not clearly formulated or understood in the first place.

11.2.6. Procedure Instructions

The last instructions part was about the procedure. I explained the timetable:

- The first 45 minutes will be a data gathering session which is about to start.
- Followed by a 15 minutes break. The first minutes of the break will be used to fill out a very brief form[233] and to handle the financial compensation that I granted the participants. The remaining part of the break can be used for recreation.
- Followed by a second data gathering of the same kind for about 30 minutes.
- Followed by an introduction to an additional *summary part* (See detailed description below).
- Finished by the *summary part* which will take approximately 10 to 15 minutes.

I didn’t use the timing information as hard break points but only approximately. When the introduction took too long I shortened the first 45 minutes a bit. When I observed on my notebook that for example a slow participant was about to reach a certain milestone in the data set I extended a phase a bit.

The data gathering session began by all participants pressing the *next* button.

233 The paper form was mainly an agreement that the data can be used in research and that the compensation was received. It also asked for the highest finished education level and if there is any association with architecture. The form is by no means a social science questionnaire. The questionnaire are the digital plates that the participants used and the data that tracked their interaction. The gathered data is quite fine grained and only a small part is used in this thesis. It might be reused for further analysis. For instance it also tracked timestamps which photographs have been looked at how long. Also if the participants have changed their mind and regrouped the ratings.

11.2.7. The Sequence of Plates

This section outlines how the four-by-one plates are composed into sequences. The term four-by-one is used to distinguish them from the six-by-one plates used in the summary which is documented in 11.2.8. A full technical documentation and a tabular visualisation of the distribution as well as a screenshot of each plate are available in Appendix D (19.4).

There are 16 curated group in the data set of 80 buildings. 8 groups have 7 members; 8 further groups have only 3 members. A curated group might have a theme like *cantilever*[234] which is the theme for group E of which the Kaleidoscope is a member. To achieve a less biased results the group are disguised by adding buildings from other groups into the plates. For instance Figure 303 shows the plate with the technical name “E3ö” and it contains two buildings from the same curated group: E5 and E6; and two buildings from other curated groups: F3 and H3.

The curated groups can be grouped into four groups:

- A Faceted, B Spike, C Hidden Simple, D Multiple
  Most members of these groups use flat surfaces
- E Cantilever, F Blob, G Concave, H Undulation
  Most members in this group use curved surfaces (Except of E Cantilever)
- S Truncation Hole, T Truncation Corner, U Penetrate Boxes, V Geometry
  Most members of these groups use flat surfaces
- W Ufo, X Bubbles, Y Spiral, Z Anticlastic
  Most members in this group use curved surfaces

We can see that A, B, C, D, S, T, U and V can be further grouped into “flat surfaces” while E, F, G, H, W, X, Y and Z can be further grouped into “curved surfaces”. These two super groups are intentional. Membership criteria in the super group is not that strict, its okay when some buildings in the curved surfaces super group consist of only flat surfaces. The driving decision for the super groups in not so much related to the current research, but rather to design a system which can be extended systematically in future data gathering sessions. It might be possible to expand groups S, T, U and V to seven members as well and have a pattern that will fill the gaps. One could include new curated groups I, J, K and L. In this way old and new gathered data can be better merged together and serve as a consistent data set.

Still the two super groups “flat surfaces” and “curved surfaces” are the foundation of the two major *tours* through the plates. There was an uncertainty concern after the beta

234 See chapter 12.1.5 for a page with all members of the cantilever curated group, as well as the other pavilions used to disguise the curated group.

tester phase: do real participants would make it through all plates in time?[235] To be certain that a good amount of data is available for all curated groups, roughly half of the participated started with plates that mainly showed “flat surfaces” at the beginning and the other half with “curved surfaces”.

Each major *tour* is made up of several *tracks*. Each track contains related plates. The idea of a track is that data is *block wise* more consistent when a participants stops at a certain time. For instance it required 6 tracks and 88 plates to get through all 80 buildings for the first time. After this milestone, additional tracks are appended which repeat the plates or add additional cross cutting plates.

The sequence of the tracks is not random. There is a risk that the sequence of the plates influences the result. For instance when all participants of the “flat surfaces” tour would start with the same plate they have the same exposure – zero – to other plates. They might be uncertain because it is the beginning of the data gathering. To mitigate the risk, randomness is introduced into the sequence in which plates appear *within one track*. Technically speaking the randomness is pseudo-randomness with a seed value. The seed value makes the randomness reproducible. The seed value used by each user is captured together with the rest of the data. There is some real human randomness as well. As I have assigned *a tour* and *a seed value* from a set of 18 predefined seed values to participants on an ad hoc basis.

11.2.8. Summary Part

There was a second phase in the data gathering sessions which I call *summary part*. It exposed the curated groups of buildings. The participants revisit a lot of pavilions that they looked at in the previous part, therefore they already had a good knowledge of the buildings and performed the task quite fast.

The summary part is not as important for my current research as the previous data gathering but it was a good occasion to test the agreement of my curated building groups with the participants. The data sets had groups with themes like: faceted (A), spike (B), hiddenSimple (C), multiple (D), cantilever (E), blob (F), concave (G) and undulation (H). See tables in the result chapter 12.1. Due to its simpler setup it is also easier to analyse the data with statistical tools.

The *summary part* introduction and the end of the data gathering session is described below:

I turned on the projector again and interrupted the previous phase. The screen showed a variation of the software used so far. Instead of four comparison buildings the users got

235 The fear was unjustified. All participants made it through both super groups and rated each of the 88 building at least once.

presented six comparison buildings. I disclosed that these are groups that I curated and that I (as the curator) think have some common features. This deliberately opinionated the participants.

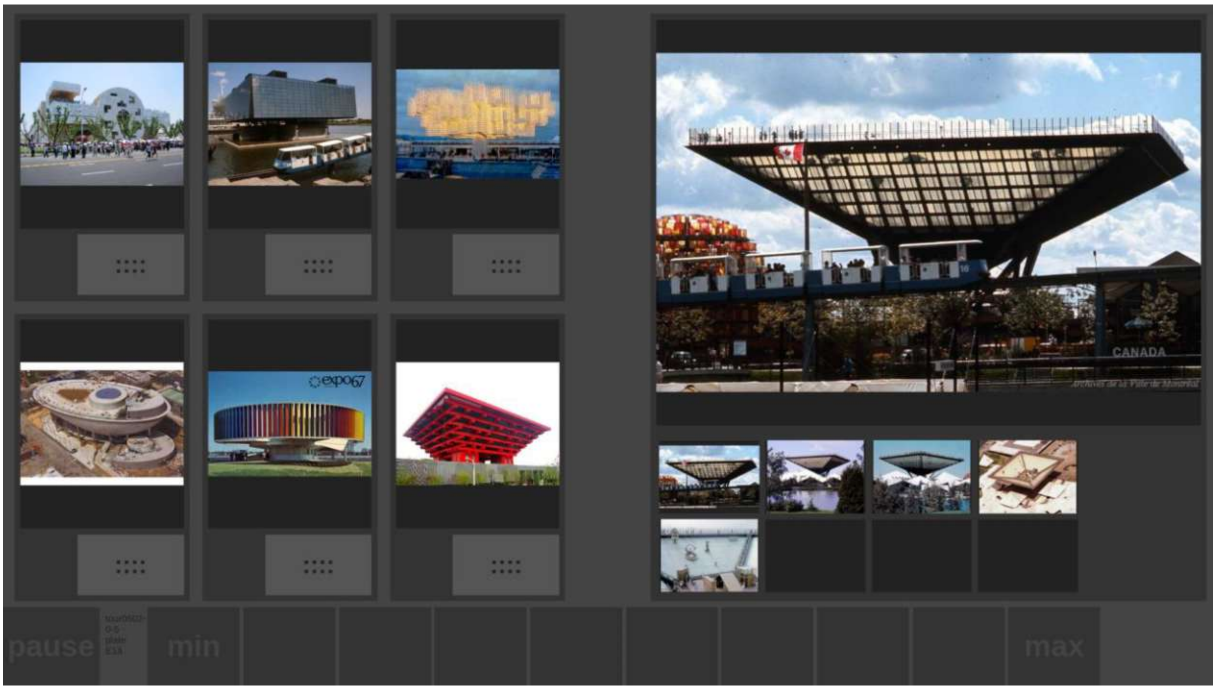


Figure 301: A summary plate. It has one focus building to the right and six comparison buildings to the left. There are ten rating slots available in the bottom row. The user interaction is identical to the foury-by-one screens with the exception that only one building is permitted per rating slot.

I explained that the rating now works slightly different. Instead of five rating boxes there are now ten rating boxes. While in the previous phase the users could group buildings into the same rating box this is not possible any more. Only one building fits into one rating box. Therefore the users must decide which building should be positioned closer to the top. The rest of the usability of the software was the same. I asked the users to take time for this summary part and hinted that there aren't so many of these plates.

There were only eight of the plates and the hint to "take time" was to slow down very fast participants. Because fast participants finished early, slower participants got peer pressure to finish soon as well. After the irregularities of the first session (described further below) I switched to a tactic: I started a little bit of small talk about the upcoming World Exposition in Milano 2015 to give slower participants a bit of time to finish their plates.

11.2.9. Irregularities

I conducted three beta test session with friends of mine before the official sessions. During beta test none of the participants reached the end of the data set. During the very first real session I had two out of five participants that finished the whole data set well ahead of time. Because they had to wait for slower participants for the summary part this lead to some distraction for the other participants. I reduced the amount of time for the whole group to handle the situation.

Also in the first group I had one participant who was very outspoken and chatty and due to my inexperience in empirical data gathering I did not manage the situation well. He distracted the other participants. In the data crunching phase I inspected the data from the first session. No obvious negative pattern could be identified.

As a consequence of the first session I extended the data set and it grew more than double in size. The new plates were only added to the end and were repetition of the central parts of the original 88 plates or additional cross connecting screens. The original first 88 plates represent one whole cycle through all my plates. I use only these 88 plates for the empirical analysis in chapter 12.

While the additional plates were mainly there to keep fast performing participants busy they might be used in other research projects as they further connect the data set together and it might be of interest to see if people *change their mind* after performing a rating again, but this time with the experience of going through the 88 original plates.

All rating results, including the additional plates are documented in Appendix C (19.3).

In one session the tablet operating system of one participant misbehaved and I needed to restart the session and try to find the approximately right position. This was cleaned up in the data afterwards.

11.3. Empirical Data for the Kaleidoscope

We will look how our canonical example "E3" Kaleidoscope was rated by the participants in the data gathering sessions. We will concentrate on two plates with the technical names "E3ä" in Figure 302 and "E3ö" in Figure 303. On these two plates the Kaleidoscope is the focus building. Also these plates deliver the data that is used in the discussion of the curated groups in chapter 12.1.

This is not the only place in which the Kaleidoscope is present. It is also present in seven more plates as a comparison building: E1ä, F2ö, G3ö, H1ü, H2ö, T3ü and Y3ü. All plates are documented and visualised in Appendix D (19.4).

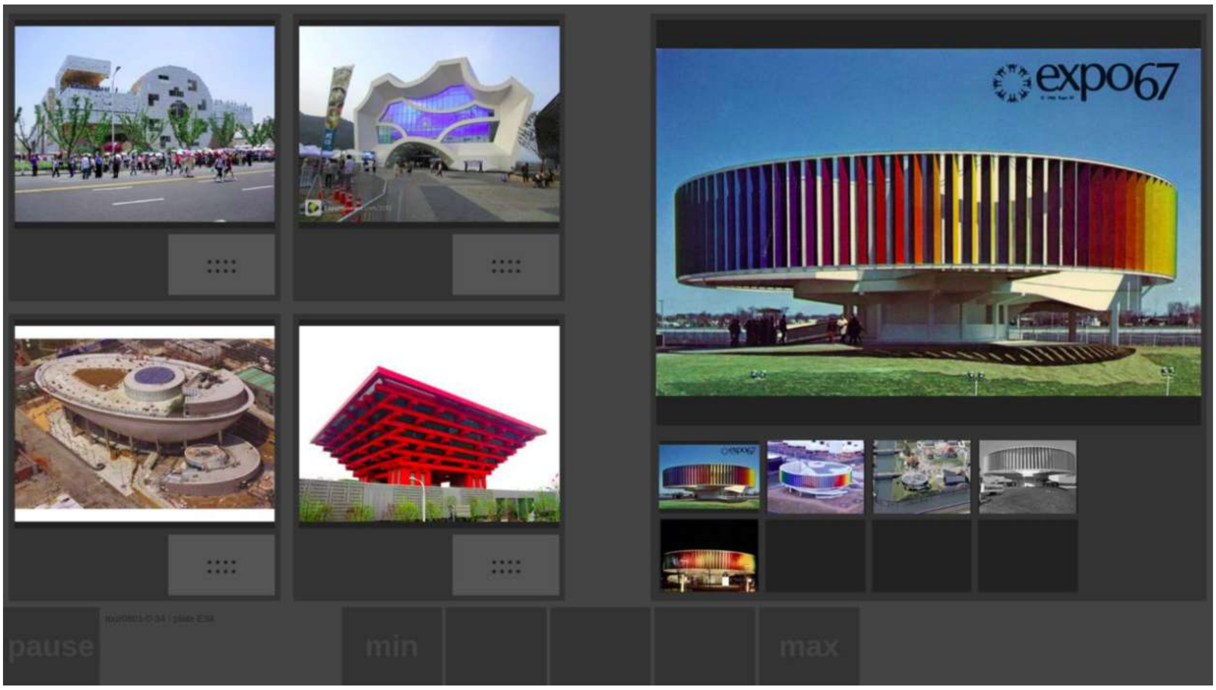


Figure 302: The plate with the technical name "E3ä" where the E3 Kaleidoscope is the focus building on the right
The four comparison buildings on the right are:
Top right: E7 - Expo 2010 South Korea Pavilion (Shanghai)
Top left: G2 - Expo 2012 Hyundai Corporate Pavilion (Yeosu)
Bottom left: E4 - Expo 2010 Saudi Arabia Pavilion (Shanghai)
Bottom right: E2 - Expo 2010 China Host Pavilion (Shanghai)

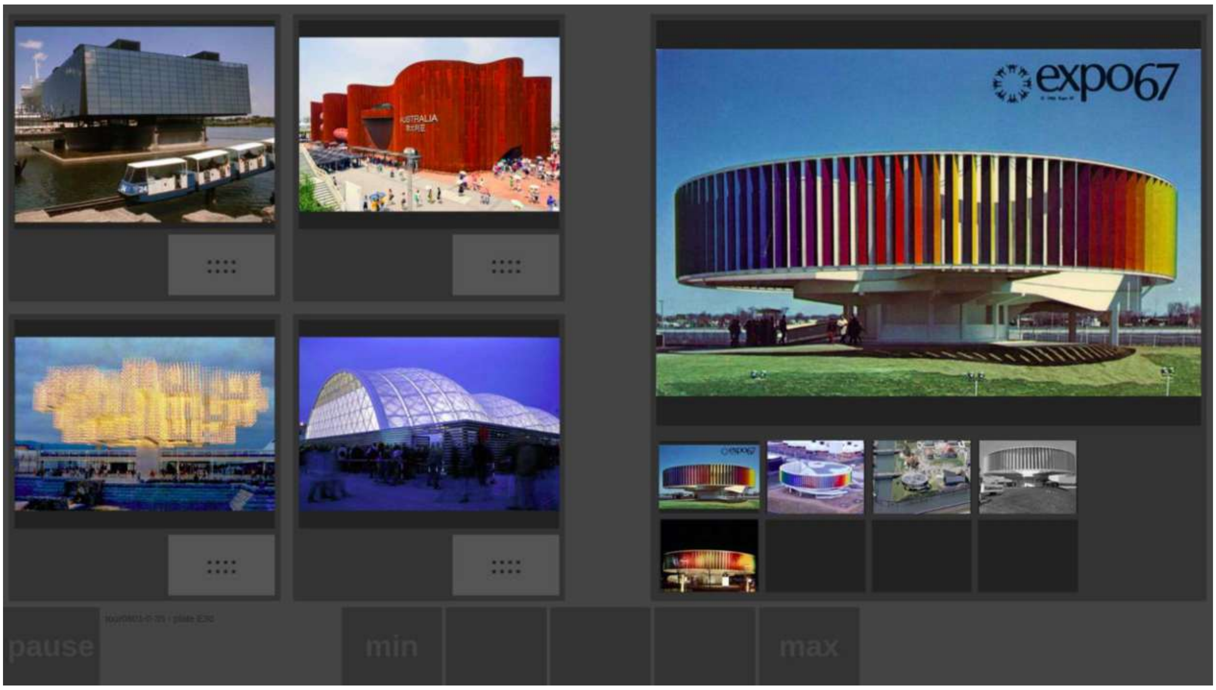


Figure 303: The plate with the technical name "E3ö" where the E3 Kaleidoscope is the focus building on the right
The four comparison buildings on the right are:
Top right: E6 - Expo 1967 Quebec Region Pavilion (Montreal)
Top left: H3 - Expo 2010 Australia Pavilion (Shanghai)
Bottom left: E5 - Expo 1970 Switzerland Pavilion (Osaka)
Bottom right: F3 - Expo 2000 Japan Pavilion (Hannover)

The following is a table with the empirical data gathered for the plate “E3ä” in Figure 302 and “E3ö” in Figure 303. The table is sorted by the mean value:

ID – Short Name	*min*	*2nd*	*3rd*	*4th*	*max*	*mean*	*std. d.*	*variance*
E4 – Saudi Arabia	2	5	20	13	9	3.45	1.04	1.09
E6 – Quebec	7	5	10	19	9	3.36	1.29	1.66
E5 – Switzerland	9	8	15	13	5	2.94	1.25	1.57
E2 – China	14	8	14	10	3	2.59	1.27	1.62
H3 – Australia	21	17	7	4	1	1.94	1.04	1.08
E7 – South Korea	30	11	6	2	0	1.59	0.86	0.75
G2 – Hyundai	29	15	3	2	0	1.55	0.79	0.63
F3 – Japan	29	17	3	1	0	1.52	0.71	0.50

An enumeration in a table is accurate but hard to interpret. Therefore all results are also visualised by a combination of a bubble chart and a bar chart. Figure 304 is a screenshot from the Appendix C (19.3). Please focus only on the first column below each building. The other columns contain data that was gathered but not used in the benchmarking. The mean value is also visualized as a diamond shape. The bar chart at the bottom shows the number of ratings. The numbers 50 and 49 roughly correspond to the number of the 52 participants. The missing deltas are due to dirty data excluded in a clean up phase. It was excluded due to irregularity or a participants pressed the *pause* button which made the plate invalid. A single *pause* affects four buildings therefore the repetition of the values 49 and 50.

Figure 304: Screenshot from Appendix C (19.3) with the first six of eight results. Please focus on the first column below each building. The aggregated number at the top are the mean value, standard deviation and variance. The diamond shape is also visualising the mean value. The bubble represent the ratings. The top bubble is equivalent to "max" value. The bottom bubble is equivalent to the "min" value. When a bubble does not contain a number then it is a "1". Please see Figure 305 for a brief description of the other columns.

 12. Discussion of Empirical Benchmarks

12. Discussion of Empirical Benchmarks

This chapter presents and discuss the measurable results that can be created by combining the output from the classification software and the empirical data. Matching the empirical data is the “goal”. The software implementation should aim to simulate it as much as possible. The smaller the delta the better the results. To distinguish the two source we will call one set *empirical data* and the other set *calculated data*.

The full empirical data that is used for the comparison can be found in Appendix C (19.3). Figures 304 and 305 show example pages from the Appendix.

The discussion also contains human interpretation and extrapolation. Many research project would benefit from large example collections and associated empirical data sets. Though these kind of data set are time consuming to create. The author hopes that the quantities of 80 World Exposition pavilion of which 32 have enough data to calculate meaningful statistical values and the 50 participants that are the source of the empirical data are meaningful loads. Still, especially when we will look into the turning on and off of *concepts* and *classification sets,* we will read that only a subset of the pavilions uses a certain feature and a better judgement would require more data.

 12. Discussion of Empirical Benchmarks

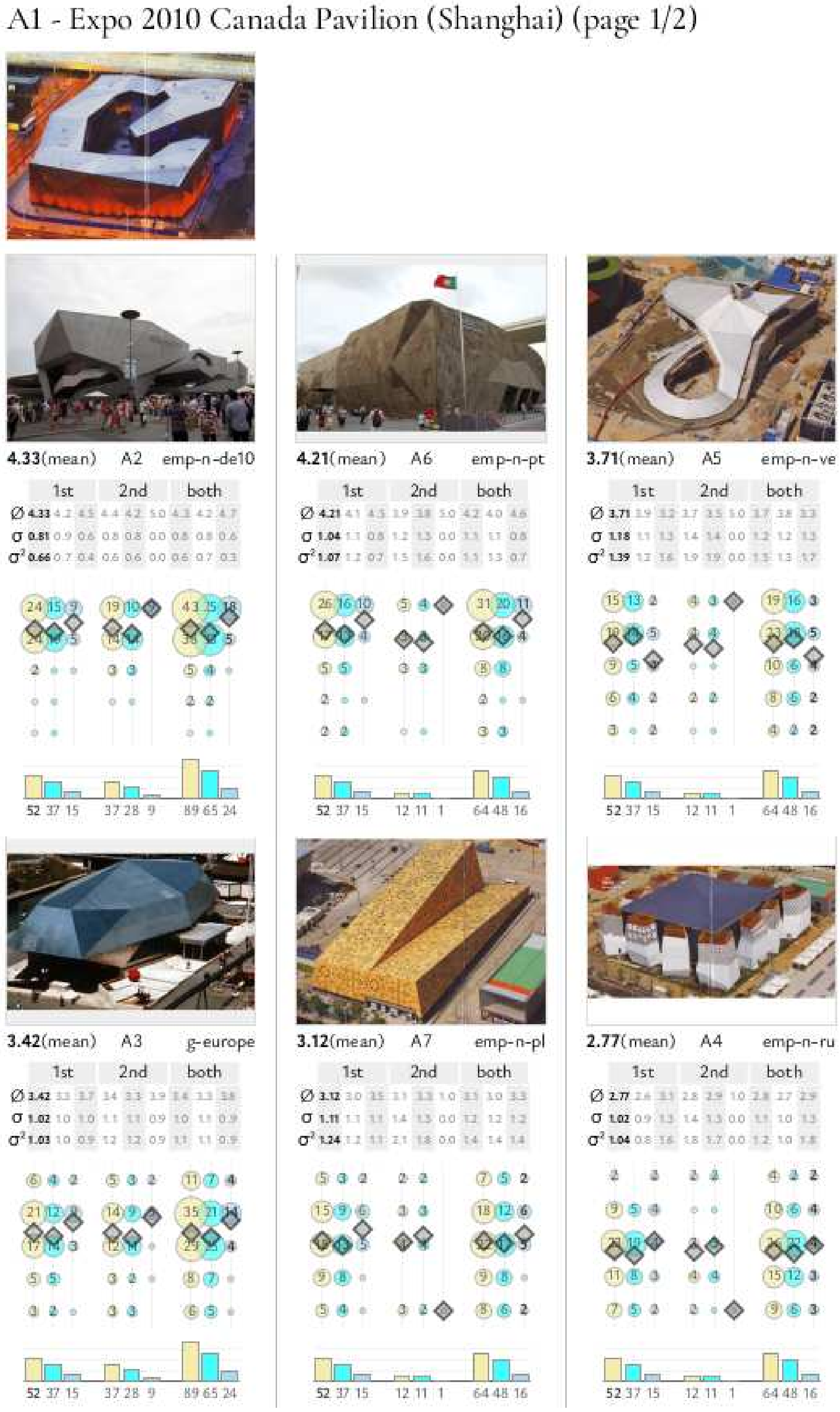


Figure 305: Example page of the gathered empirical data from Appendix C (19.3). The most left column with the bold font is the data used for the comparison with the software data (see also caption of Figure 304). All other columns are present to show potentials for future research. The columns grouped as "1st" are from the first encounter of the participants with this rating tasks. Faster participants might have done the rating twice ("2nd") and might have changed their mind. An aggregate of "1st" and "2nd" is given in the columns grouped as "both". Each group itself is split up for a column which does not distinguish the background of the participants. Then followed by a column with participants with an educational background with architecture. The third column is from participants without an architecture background.

 12. Discussion of Empirical Benchmarks

The chapter follows the structure:

- *Introduction* – We will discuss how the empirical data and the calculated data are mapped and aligned, in a way that delta values can be calculated. This is best done in context by looking at Table 21 which uses the same data as the first real table of the curated group results.
- *Curated groups* – 16 tables of the curated groups are presented and some interesting results are marked up and discussed in subchapter 12.1. Reading through this subchapter will make the reader familiar with the 80 World Exposition pavilions. This should make it easier to follow the following subchapters. The numeric results in Tables 22 up to 37 are the *overall* result. With all classification sets and concepts activated in the software.
- *Concepts* - There is not one but a group of concepts introduced in this thesis. We can turn separate concepts on and off and see how much they contribute.
- *Classification sets* - The thesis uses ten classification sets for in Building Shape Periphrase and six classification sets in Building Shape Syntax Tree. It is possible to look at the performance of each single classification set. We can follow how much it contributes to the overall result. We can turn it off, turn it on, or turn all other classification sets off.
- *Subsets* - A last subchapter investigates and discusses if certain subsets of classification sets and concepts might already be sufficient to have meaningful results. There is also be a discussion if it is easier to predict certain percentiles.

We need to map between the empirical numbers and the software numbers. The participants in the data gathering had slots for the values 1,2,3,4 and 5. They have been instructed to use the "5" even if the two buildings are not identical, but rather highly related in their building shape. There are no two buildings with exactly the same shape in the empirical data set.

There have been multiple attempts to map the software data against the empirical data, and the following pattern was chosen because it seems to be fair and balanced. The text associated with Table 21 will describe the mapping within the example of group A.

We can define an upper bound and a lower bound. The upper value would be an ideal 0%. There would be a delta of 0%. This would state that the calculated data can match the empirical data completely. A lower bound of 100% delta would mean that each calculated value is 100% off. This is not possible for values which are in the middle. It would be possible to calculated a maximum off value with some maths per curated group or subset, but this is not tangible. Therefore we define a different *zero*.

 12. Discussion of Empirical Benchmarks

The lower reference is sometimes name *zero* in the tables and figures. It does not define a numerical zero but is rather a “when we do zero work; invest zero effort”. It is a constant containing the mean of all empirical values in a group. For instance in a group of three buildings with empirical data 3.1, 2.0 and 1.5, the mean value would be 2.2. The *zero work* approach would be: When we would be a gambler and we would have insider information that the statistical average is 2.2 it would be a safe and lazy bet to do nothing and always shout out the average value, when asked what the empirical data might be for any given pair. So this virtual lazy gambler is the lower reference point that the software implementation is competing against. This also means that the calculated data can even be sometimes worse then the lazy gambler value.

Figure 306 and Figure 307 visualise the pictograms. Their roles in the tables is introduced in the text following Table 20.

Only the first round is used – The full empirical data gathering is described in chapter 11.2, and the data used for this statistical analysis only contains the *first round*, which all 52 participants finished. There are additional plates which also connected the A, B, C, D to the E, F, G ,H and a *second round* of very fast participants which are not utilized here.

Aggregated tables – After the pages with the 16 curated groups follows an aggregated view. The aggregation only contains A1, A2, A3 from the group A and only S1 for the smaller group S. These are the members with enough empirical data. Therefore on aggregated pages we see only 32 pavilions. It worth mentioning that a lot of information is lost by looking only at the aggregated tables and a lot *small insights* are present in the curated groups tables.[236]

Circles markup – A lot of tables contain circles as markup with numbers “1, 2, 3, …” and sometimes additional qualifying characters like “1a, 1b, 1c”. These markups are picked up in a simplified text form like “(1)” or “(2a)” on the text paragraphs following the table and an interpretation of the given numbers is given.

The numbers given in the tables are rounded. For instance 4.39122 becomes 4.4 and 3.99999% becomes 4%. The software does of course use the decimal values in all its calculation. This makes the visual appearance of the tables lighter.

236 The aggregated views will do a lot of experiments, like turning different classification sets on and off. For a deeper insight this would require to reprint each of the 16 curated Tables 22 up to 37 over and over again. These exceeds the limits feasible for a print publication. These deeper drill down is possible in the running software which generates the aggregated views.

12. Discussion of Empirical Benchmarks

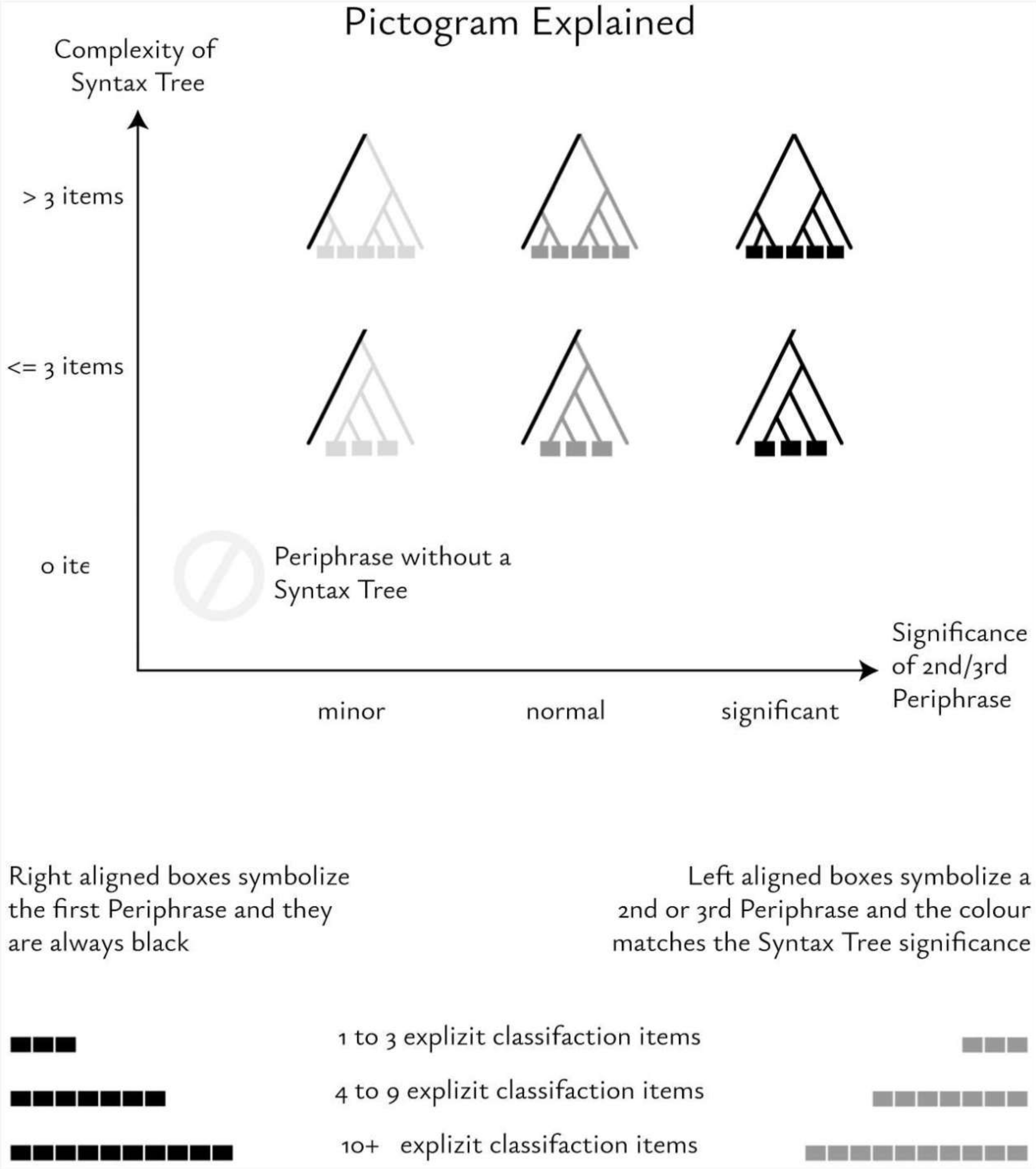
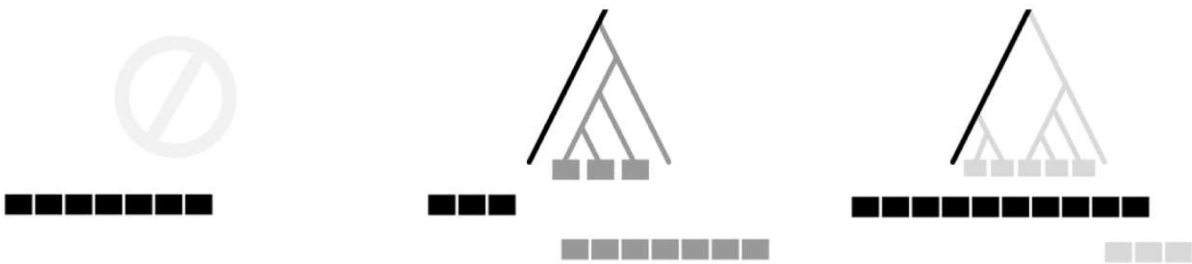


Figure 306: Explaining the parts of the pictogram used in the following tables



a: Just a Periphrase with an average amount of items

b: Simple Syntax Tree with more items in the 2nd Periphrase than in the 1st one

c: Complex Syntax Tree but the 1st Periphrase is much more important and has many items

Figure 307: Pictogram examples

12.1. Results of Curated Groups

The following pages contain tables of 16 curated groups of World Exposition pavilions. The groups have a character (A, B, C, ...) as their identifier. Each group is introduced and discussed in text in the paragraphs following the table. Each group also has a short tag like *faceted*, *spike*, *hiddenSimple*, etc. that hints the common property and is sometimes used as a back-reference.

Pages with seven pavilions

The groups A, B, C, D, E, F, G, H contain seven pavilion. These are the major groups. We use the prefix “A” as an example. The pavilions are numbered like “A1, A2, A3, ...”. Due to the empirical setup only the first three pavilions have enough empirical data to be used in aggregated statistical analysis. The pavilions with higher number like A4, A5, A6, A7 are *supporting* buildings. They are part of the curated group and they all are compared to the primary three pavilion. They always show up in the columns dedicated to A1, A2, A3.

Pages with three pavilions

The groups S, T, U, V, W, X, Y, Z only contain three pavilions. We use the prefix “S” as an example. These are also groups with a common curated theme like *spiral, bubble, truncationCorner*. But there wasn’t enough buildings to form a group of seven, or the group was considered of less interest at this stage of the research. For these groups only the first building like S1 has enough empirical data to be used in aggregated statistical analysis. S2 and S3 are *supporting* pavilions. They always appear in the column of S1, so the group in itself can be analysed for first trends.

Pavilions from other groups

To disguise the curated groups from the participants of the data gatherings, each curated group also contains pavilions from other groups. For instance in the “A” group we also find B1, B2, B3, C1, C2, D1, D2, D3. The exact pattern and objective is described in Appendix D (19.4) but please note that the groups A, B, C, D are connected with each other and E, F, G, H are connected with each other. Though these two super-groups are not connected but stay in silos. This setup would allow further groups to be introduced in the future, like the missing I, J, K, L. Or the small groups S, T, U, V, W, X, Y, Z could be expanded to full seven-member groups.

For the groups A to H the text is about the length of a print page and references the table on the previous page[237]. The intentions is to have the table and text next to each other on spreads in a print publication. For groups S to Z, table and text fits on one page each.

237 Exception is group “E” as it contains our canonical example, the Kaleidoscope. It gets some additional pages.

The text paragraphs of the results tables for A to H will begin with a few sentences that describe the curated group. Then a review how the curated group performed. The word *perform* is taken here softly as in: "Did the participants recognized the same group that the curator did assemble?" This is usually the case when the curated group can be found at the top ranks of the result lists. Otherwise it will be mentioned in the text. The text for the smaller groups S to Z, is shorter and less detailed.

When we refer to values like standard deviation, then details backing these values can be looked up in Appendix C (19.3). The standard deviation concerns only the empirical data and has no connection to the calculated data. Still a high standard deviation (like 1.37) is an indicator that there was no agreement by the participants. For a calculated value we can infer: Having an outlier value for a high empirical standard deviation is *not that negative*, then having an outlier for a low empirical standard deviation with a lot of agreement among participants. When we call out a number of participants, please be aware that the total number of all participants is 52.

We will use the terms *overrating* and *underrating*. For *overrating* it means that the calculated value is higher then the associated empirical value. The empirical value is sourced from the empirical data gatherings of the 52 participants. The software claims more similarity then the empirical data does. *Underrating* is the same pattern for calculated values which are to low.

In the text we will see cryptical technical terms like cardApproximatly13OrMore. They are written in an italic font and either references one of the sixteen classification sets or items from within these classification sets. The definitions can be looked up in chapter 7.3 for Periphrases and chapter 8.2 for Syntax Trees.

Before we start with the real data (A, B, C, ...) there are two describing tables marked "?1" and "?2" with accompanying text paragraphs. The first describes the layout, table columns and pictograms. The second describes the numbers and colour coding. The describing tables use group A as their data example. It should be easier to transition to the real table A which follows it.

?1

A1 - Expo 20 2a anada Pavilion (Shanghai)

6

Ø 8%

Ø 9%

5

id	pic	emp	delta	calc
A2		4.3	15%	3.7
A6		4.2	3%	4.3
A5		3.7	3%	3.8
A3		3.4	1%	3.4
A7		3.1	20%	2.3
A4		2.8	7%	3.1
D1		2.1	10%	1.7
C1		1.8	12%	1.4
B2		1.8	9%	2.1
B1		1.7	21%	2.5
B3		1.5	2%	1.5
C2		1.4	10%	1.8

?1

Faceted

1

A2 - Expo 2 2b Germany Pavilion (Shanghai)

Ø 13%

Ø 9%

id	pic	emp	delta	calc
A6		4.2	0%	4.2
A5		3.6	13%	4.1
A7		3.2	6%	3.0
A4		2.5	33%	3.8
B2		2.1	18%	2.8
D2		1.9	0%	1.9
B3		1.8	2%	1.7
D3		1.3	0%	1.3

4

A4 - Expo 2010 Russia Pavilion (Shanghai)

A6 - Expo 2010 Portugal Pavilion (Shanghai)

A3 - Expo 196 2c urope Pavilion (Montreal)

Ø 13%

Ø 12%

id	pic	emp	delta	calc
A6		4.3	0%	4.3
A2		4.1	25%	3.1
A7		3.1	12%	2.6
A5		3.1	13%	2.5
A4		2.3	13%	2.8
B3		1.7	21%	2.6
D3		1.4	8%	1.8
C2		1.2	0%	1.2

3

A5 - Expo 2010 Venezuela Pavilion (Shanghai)

A7 - Expo 2010 Poland Pavilion (Shanghai)

Table 20: Introduction to curated results – Layout ?1

?1 – Layout introduction

The tables contain black markup circles. There is a convention in the numbering of the circles. The number "1" in "(1a)" is as it appear in the text on the following page. The suffix "a" in "(1a)" corresponds first column, "b" to the second column and "c" to the third column. Sometimes a "d", "e", "f" are present as well, but then the column is mentioned in the text. The circles themself appear as a stylized text in the text like (1a).

(1) – In the lower left corner of the print page, there is some white space that is utilized for headlines. The identifying character of the group is given as well as a short tag like "Faceted". The tag hints the common theme for a curated group.

(2) The pavilions A1 (2a), A2 (2b), A3 (2c) have enough empirical data and get their own columns that span most of the page height. The first column has twelve buildings, while the other two columns have eight. We see a photograph of the building together with its id "A1", as well as the World Exposition year "Expo 2010". A nation pavilion name is written like "Canada Pavilion" rather then "Canadian Pavilion".[238] The last caption information is about the city that hosted the Expo, like "Shanghai". We will refer to the data as "first column", "second column" and "third column". The rows are sorted by the "emp" value, which is the empirical value gathered from the 52 participants.

(3) – The four supporting buildings A4, A5, A6, A7 are in the lower right corner (3) of the page. They are all of the same importance and their order is arbitrary.

(4) – The "id" column shows values like "A4" and "B2" (4). Buildings of the same curated group are in bold, and buildings from other groups are in normal font weight. In the given example it is easy to grasp that all curated group members accumulate at the top of the list.

(5) – The pictogram column (5) is an idealized indication of building shape classification data. The pictograms are explained in Figure 306. Please be aware that they are not miniature versions of the real Syntax Tree and Periphrase but idealized visualisation. They should give the reader a feeling, how simple or complex the underlying classification is. Figure 307 provides pictogram examples with brief explanations. The pictograms only appear in the first column to safe print layout space. All curated peers A2, A3, A4, A5, A6, A7 will always be present in the first column, so its possible to look up their pictogram there. The photographs are tiny in the "pic" column and the easiest way to see the bigger photograph is to flip to the neighbouring curated pages. Appendix A (19.1) provides additional photographs for each building.

(6) – (6) Is the pictogram of A1 itself.

238 This is a common approach on World Expositions, as many visitors might not have English as their native language and using the simpler nouns is easier for them.

?2

A1 - Expo 2010 Canada Pavilion (Shanghai)

Ø 8%

Ø 9%

id	pic	emp	delta	calc
A2		4.3	15%	3.7
A6		4.2	3%	4.3
A5		3.7	3%	3.8
A3		3.4	1%	3.4
A7		3.1	20%	2.3
A4		2.8	7%	3.1
D1		2.1	10%	1.7
C1		1.8	12%	1.4
B2		1.8	9%	2.1
B1		1.7	21%	2.5
B3		1.5	2%	1.5
C2		1.4	10%	1.8

?2

Faceted

A2 - Expo 2010 Germany Pavilion (Shanghai)

Ø 13%

Ø 9%

id	pic	emp	delta	calc
A6		4.2	0%	4.2
A5		3.6	13%	4.1
A7		3.2	6%	3.0
A4		2.5	33%	3.8
B2		2.1	18%	2.8
D2		1.9	0%	1.9
B3		1.8	2%	1.7
D3		1.3	0%	1.3

A4 - Expo 2010 Russia Pavilion (Shanghai)

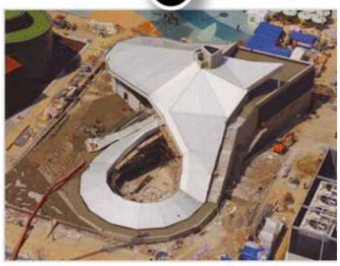
A6 - Expo 2010 Portugal Pavilion (Shanghai)

A3 - Expo 1967 Europe Pavilion (Montreal)

Ø 13%

Ø 12%

id	pic	emp	delta	calc
A6		4.3	0%	4.3
A2		4.1	25%	3.1
A7		3.1	12%	2.6
A5		3.1	13%	2.5
A4		2.3	13%	2.8
B3		1.7	21%	2.6
D3		1.4	8%	1.8
C2		1.2	0%	1.2



A5 - Expo 2010 Venezuela Pavilion (Shanghai)

A7 - Expo 2010 Poland Pavilion (Shanghai)

Table 21: Introduction to curated results – Numbers and colour coding ?2

?2 – Numbers and colour coding introduction

At the top of the delta column, above the word “delta”, there is an aggregated mean like “9%”. The lower the number the better. This is also the value that will be use in the aggregated views in later subchapters. The light grey number above it is the mean of only the curated group itself. It is usually better then the one of all involved buildings.

(1) The numbers in the “emp” (empirical average) column (1a), (1b), (1c) will range between 5 and 1 and represent a mean of all 52 participants. “5” is the highest similarity that the participants could assign, while “1” is the lowest. The Example of the A1 Canada Pavilion is quite typical with the best value at 4.3 (1a) and the worst value at 1.4 (2a). When the values have a unusual range then this is discussed in the associate text.

(2) There was no zero value in the empirical data gathering setup. So values at the lower end are always above or equal to 1.0 (2a), (2b), (2c).

(3) The “calc” column (3a) shows the data that is calculated by the software implementation which is part of this thesis. The values are remapped, as discussed further above. There will always be two values in the “calc” column that correspond to the top/last values in the “emp” column. For example 4.3 in (1a)-to-(3d), and 1.4 in (2a)-to-(3c). The “delta” column shows how much *off* the calculated value is from the empirical value. For instance “15%” for (3a) and “3%” for (3b). The column is colour coded with a temperature gradient from green via yellow to red. The colour gradient should help identity top performer and outlier. It was adjusted so there is enough visual variation. The gradient shows everything with more then 30%as a pastel red. The pastel red starts approximately at the same value as the “lazy zero”.

(4) Sometimes we can see a delta of 0% in the top result like in (1c) and (4b). This indicates that the empirical data as well as the software have an agreement that this is the building with the most similarity. It does not mean that the calculated value itself was also 4.2 on a range between 5 and 1. Please see the “remapping” paragraphs at the start of chapter 12 for details. Still a 0% is a positive indicator.

Sometimes we can see a delta of 0% in the last result like in (2b) and (2c). This indicates that the empirical data as well as the calculated data have an agreement that this is the building with the least similarity.

(5) Sometimes we can see a delta of 0% in the middle (5b). This is a “nice” coincident. Please be also aware that due to the mathematical floor rounding this value might by a 0.999%.

A

A1 - Expo 2010 Canada Pavilion (Shanghai)

Ø 8% 1a Ø 9%

picto	id	pic	emp	delta	calc
	A2		4.3	15%	3.7
	A6		4.2	3% 2a	4.3
	A5		3.7	3% 4a	3.8
	A3		3.4	1%	3.4
	A7		3.1	20% 5a	2.3
	A4		2.8	7%	3.1
	D1		2.1	10%	1.7
	C1		1.8	12%	1.4
	B2		1.8	9%	2.1
	B1		1.7	21% 6a	2.5
	B3		1.5	2%	1.5
	C2		1.4	10%	1.8

A2 - Expo 2010 Germany Pavilion (Shanghai)

Ø 13% 1b Ø 9%

id	pic	emp	delta	calc
A6		4.2	0% 2b	4.2
A5		3.6	13%	4.1
A7		3.2	6%	3.0
A4		2.5	33% 3b	3.8
B2		2.1	18%	2.8
D2		1.9	0%	1.9
B3		1.8	2%	1.7
D3		1.3	0%	1.3

A3 - Expo 1967 Europe Pavilion (Montreal)

Ø 13% 1c Ø 12%

id	pic	emp	delta	calc
A6		4.3	0% 2c	4.3
A2		4.1	25%	3.1
A7		3.1	12% 5c	2.6
A5		3.1	13%	2.5
A4		2.3	13%	2.8
B3		1.7	21%	2.6
D3		1.4	8%	1.8
C2		1.2	0%	1.2

A4 - Expo 2010 Russia Pavilion (Shanghai)

A5 - Expo 2010 Venezuela Pavilion (Shanghai)

A

Faceted

A6 - Expo 2010 Portugal Pavilion (Shanghai)

A7 - Expo 2010 Poland Pavilion (Shanghai)

Table 22: Results of curated group A – Faceted
Contains pavilions A1, A2, A3, A4, A5, A6, A7
Empirical data and calculated data for A1, A2, A3

12.1.1. A – Faceted

Common characteristics: The shapes are dominated by flat elements that usually do not have 90 degree angles at their corners (textureFacetedIrregular). *Tilt* is present to various degrees in all building shapes. In many cases multiple Tilt items are applied. Most buildings do not have strict upright outer walls (*Tilt*, *Angle-View*), except for A5 and the central hall in A4.

(1) At 9% (1a), 9% (1b) and 12% (1c) this curated group performs good, in all three columns. Usually the peer members of a curated group perform better then the whole mixed setup with members from other groups. But this is not the case here. This is due to the outlier from the curated members that we will discuss below.

(2) A6 - Expo 2010 Portugal Pavilion (Shanghai) perform well in all three columns (2a), (2b), (2c). This causes problems for A2 in the first (2a) and third column (2c). Due to the remapping of the values which A6 causes, the second building has a gap of 0.6 in the first column and even 1.2 in the third. The software manages to ranks the complex A2 Germany Pavilion at the second place with a value of 4.2 (2a), but the delta and colour coding to the empirical data gives a negative impression, which is not fully justified. The building shape for A2 Germany Pavilion is challenging. Still it has a very low standard deviation of 0.81 against the A1 Canada Pavilion in the first column (2a). There is agreement by the participants that these buildings relate. A2 perform good in its own second column as well. Except of the outlier A4 (3b).

(3) A4 - Expo 2010 Russia Pavilion (Shanghai) is overrated in the second column by the software by 33% (3b). The software does compare a single Russian “identity tower” to the main distinct building part of the A2 Germany Pavilion. The complex Syntax Tree composition which is important to A4 is not taken enough into account. For instance the fact that there are 12 related Russian identity towers can not be handled appropriately.

(4) A5 - Expo 2010 Venezuela Pavilion (Shanghai) has the highest standard deviation in the first column (4a) when compared to A1 Canada Pavilion. Six participants even rated it with “1” and another three with “2”. It might be that the participants struggled with the combination of upright walls and faceted roof.

(5) A7 - Expo 2010 Poland Pavilion (Shanghai) is modelled as a composition of two distinct building parts. It does not perform as well in (5a) and (5c). Maybe a modelling as a single Periphrase with a significant featureValleySingle would improve the situation.

(6) B1 - Expo 1970 Soviet Union Pavilion (Osaka) has unexpected low empirical data in the first column (6a). The participants might not have taken the faceted properties in the pavilion as significant and might have concentrated on other aspects like the spike (featureHighpointSingle). The software uses a lot of classification items which are also common in the A Group. Therefore it overrates the building.

B

B1 - Expo 1970 Soviet Union Pavilion (Osaka)

Ø 10%

Ø 9%

picto	id	pic	emp	delta	calc
	B7		4.3	0% (2a)	4.3
	B3		4.1	10%	3.7
	B2		3.7	40% (1a)	2.1
	B5		3.6	6% (3a)	3.9
	B6		3.4	4%	3.2
	B4		2.8	2% (4a)	2.7
	D1		2.5	4%	2.3
	C3		2.0	8%	2.3
	A1		1.9	12%	2.4
	D2		1.8	13%	2.3
	C1		1.4	8%	1.1
	C2		1.1	1%	1.1

B2 - Expo 1967 United Kingdom Pavilion (Montreal)

Ø 10%

Ø 19% (1b)

id	pic	emp	delta	calc
B5		3.6	2% (3b)	3.6
B7		3.0	16% (2b)	2.3
B6		2.4	18%	3.2
A4		2.3	34%	3.6
B4		2.2	5% (4b)	2.4
A3		2.0	10%	1.6
C2		1.7	27%	2.7
C3		1.6	44% (1d)	3.4

B3 - Expo 1970 Philippines Pavilion (Osaka)

Ø 9%

Ø 9%

id	pic	emp	delta	calc
B7		4.5	0% (2c)	4.5
B6		4.0	15%	3.4
B5		3.3	4% (3c)	3.1
B4		3.1	8% (4c)	2.8
B2		2.4	21% (1c)	1.6
A5		1.8	3%	1.6
D2		1.7	8%	2.1
C3		1.6	14%	2.2

B4 - Expo 2010 Malaysia Pavilion (Shanghai)

B5 - Expo 2010 Luxembourg Pavilion (Shanghai)

B

Spike

B6 - Expo 1958 Fleche Du Genie Civil (Bruxelles)

B7 - Expo 1958 Philips Corporate Pavilion (Bruxelles)

Table 23: Results of curated group B – Spike
Contains pavilions B1, B2, B3, B4, B5, B6, B7
Empirical data and calculated data for B1, B2, B3

12.1.2. B – Spike

Common characteristics: All building have at least one spike or tower like structure (featureHighpointSingle). B4 and B7 have multiple high points (featureHighpointMultiple). Many members have a featureRidgeSignificant and tapering *Tilt* items. Five members are asymmetrical and have *Lattice* transformation like laticeStrechUnproportional or latticeShear.

Curated members performs well. The members appear at the top of all three columns.

(1) B2 - Expo 1967 United Kingdom Pavilion (Montreal) is the obvious outlier in the first (1a) and third column (1c), as well as in its own second column (1b). It is challenging the proposed classification system. It has a common visual language, but this might also be transported by aspects that are not related to building shape; like the white colour. The white colour is also present in the B1 Soviet Union Pavilion. With 19% (1b) delta in its aggregated mean, it is one of the most poorly performing buildings. A drastic pair is B2-to-C4 France Pavilion; It is off by 44% (1d). It is rated very low in the empirical part but is overrated by the software due to matches on the Syntax Tree and second Periphrase.

(2) B7 - Expo 1958 Philips Corporate Pavilion (Bruxelles) performs well in the first (2a) and third column (2c). This might be an indication that the system proposed in this thesis works well. The values tiltTaperComplete, edgeSharp, featureHighpoint, latticeUstrech are contributing the bulk of the similarity. The soft hyperbolic surface of B7 does not contribute in the first column (2a), as the B1 Soviet Union Pavilion has flat surfaces. In the third column (2c) it matches so well that there is a significant gap forced onto the second building. This is similar to A6 in the A group. In the second column (2b) of the problematic B2 United Kingdom Pavilion it has a high standard deviation of 1.22. Five participants rated it “5” and at the same time seven participants rate it “1”.

(3) B5 - Expo 2010 Luxembourg Pavilion (Shanghai) performs well and is benefiting from both, Syntax Tree and Periphrases. In the first (3a) and third column (3c) the inner building is matched against B1 and B3 which do not have a Syntax Tree. In the second column (3b) the secondary distinct building part is contributing ~24%. Another ~15% are coming from the composition items.

(4) B4 - Expo 2010 Malaysia Pavilion (Shanghai) performs well in all three columns (4a), (4b), (4c). Even though only in the middle and not in the top of the ranked list. It is also rated in the middle by the participants of the empirical data gathering.

C

C1 - Expo 2010 Angola Pavilion (Shanghai)

Ø 6% / Ø 7% (1a)

picto	id	pic	emp	delta	calc
	C6		3.3	2% (3a)	3.3
	C4		3.2	3%	3.0
	C7		3.1	4%	3.3
	C2		3.0	9% (2a)	3.3
	A1		2.1	12%	1.6
	C3		2.0	13%	2.5
	A2		1.9	11%	2.3
	D1		1.9	3%	1.8
	D3		1.8	6%	2.0
	B1		1.6	1%	1.5
	D2		1.6	21% (4a)	2.4
	C5		1.5	2%	1.6

C2 - Expo 2010 Algeria Pavilion (Shanghai)

Ø 6% / Ø 14% (1b)

id	pic	emp	delta	calc
C7		4.4	1%	4.3
C6		4.2	3% (3b)	4.4
C4		3.2	17%	3.8
A2		1.8	21%	2.7
B3		1.6	8%	1.3
D3		1.5	14%	2.1
C5		1.4	4%	1.6
D2		1.3	44% (4b)	3.0

C3 - Expo 1967 France Pavilion (Montreal)

Ø 3% / Ø 5% (5c)

id	pic	emp	delta	calc
C5		2.6	0%	2.6
A2		2.5	5%	2.3
A3		2.2	8%	2.5
C4		1.6	7%	1.4
C6		1.6	4%	1.4
C7		1.4	0%	1.4
D3		1.4	15%	2.0
C2		1.4	2%	1.4

C4 - Expo 2010 Monaco Pavilion (Shanghai)

C5 - Expo 2010 Israel Pavilion (Shanghai)

C

Hidden Simple

C6 - Expo 2010 Croatia Pavilion (Shanghai)

C7 - Expo 2010 Sri Lanka Pavilion (Shanghai)

Table 24: Results of curated group C – Hidden Simple
Contains pavilions C1, C2, C3, C4, C5, C6, C7
Empirical data and calculated data for C1, C2, C3

12.1.3. C – Hidden Simple

Common characteristics: We have discussed these buildings in chapter 10.5. As a summary: There is always a bigger block which houses the main exhibition. At the front there is an identity tower and a porch. The buildings are then "decorated" to give them identity. Two unrelated buildings C3 and C5 have been added to disguise the group, to make the characteristic less obvious for the participants of the empirical data gathering.

(1) The real *hidden simple* members perform well in the first (1a) and second column (1b). We can assume that the empirical participants "looked through" the decoration for C2 - Expo 2010 Algeria Pavilion (Shanghai). The proposed classification system gives enough attention to the main building shape which are just boxes.

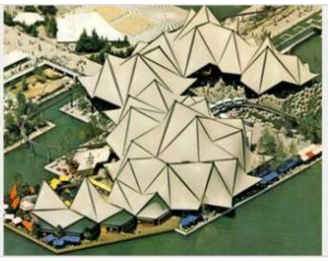
(2) C1 - Expo 2010 Angola Pavilion (Shanghai). The curated members in the first column have high standard deviations. For instance the pair C1-to-C2 (2a) has a standard deviation of 1.34. This is the second highest standard deviation of the 32 main pavilions. So the participants were uncertain about the decoration. For instance nine participants rated C1-to-C2 with a "5" and at the same time ten participants with a "1".

(3) C6 - Expo 2010 Croatia Pavilion (Shanghai) has the identity tower on the left hand side while C1 Angola Pavilion and C2 Algeria Pavilion at the right hand side. The participants did not care (3a), (3b). The decision to leave out detailed composition information out of the *Spacing* classification set might be backed by this. No definition of *front*, or distinction between left and right, appears to be a valid choice.

(4) D2 - Expo 1967 Africa Group Pavilion (Montreal) gets false positives (4a) (4b) from the fact that it also has a broad Syntax Tree. Many values in the Periphrases that snap into the default classification items are contributing upwards. This might be a weakness of the *strong independence assumption* in the proposed system.

(5) C3 - Expo 1967 France Pavilion (Montreal) was added to the group to disguise it. Still it performs surprisingly well with 5% (5c) in its mean value. But this is caused by the way we remap to the empirical results. C3 has a range from just 2.6 to 1.4. But even without the remapping we can see that the *hidden simple* are all at the bottom. This is reasonable because C3 is a *distraction* item. C3 has a big Syntax Tree. The two towers that are hard to see on the aerial picture in the table are modelled as independent distinct building parts. See additional photograph in Figure 322 where this is more obvious. Additional photographs in Appendix A (19.1).

D



D1 - Expo 1967 Ontario Region Pavilion (Montreal)

Ø 8%

Ø 12%

picto	id	pic	emp	delta	calc
	D7		4.2	0%	4.2
	D3		4.0	5%	4.2
	D2		3.9	2% (2a)	4.0
	D5		3.0	10%	3.4
	B1		2.7	28% (3a)	1.6
	A2		2.5	4%	2.3
	A3		2.4	25% (3d)	1.4
	A1		2.1	18%	1.4
	D6		2.0	12% (4a)	2.5
	B2		2.0	7%	2.2
	D4		1.9	17% (1a)	2.6
	C1		1.4	10%	1.8

D

Multiple

D2 - Expo 1967 Africa Group Pavilion (Montreal)

Ø 9%

Ø 12% (2b)

id	pic	emp	delta	calc
D5		3.8	2%	3.7
D7		3.2	15%	3.8
D6		3.0	12% (4b)	2.5
D4		2.5	7%	2.2
A3		2.1	21%	1.2
B2		1.8	5%	1.9
C4		1.4	11%	1.8
C3		1.2	21%	2.1

D4 - Expo 2010 Wanke Corporate Pavilion (Shanghai)

D6 - Expo 2010 Netherlands Pavilion (Shanghai)

D3 - Expo 1967 Pulp and Paper Corporate Pavilion (Montreal)

Ø 5%

Ø 9%

id	pic	emp	delta	calc
D7		4.5	0%	4.5
D2		3.4	20% (2c)	4.2
D5		3.0	6%	3.3
D6		2.4	1% (4c)	2.5
B3		2.1	23%	1.2
D4		1.9	1%	2.0
B2		1.9	4%	1.7
C5		1.2	20%	2.0

D5 - Expo 2010 Cases Theme Pavilion (Shanghai)

D7 - Expo 1970 Bulgaria Pavilion (Osaka)

Table 25: Results of curated group D – Multiple
Contains pavilions D1, D2, D3, D4, D5, D6, D7
Empirical data and calculated data for D1, D2, D3

12.1.4. D – Multiple

Common characteristics: Members all have broad Syntax Trees. Often high *Cardinality* like cardApproximatly13OrMore augments the *Spacing* branches. Members utilise the *Variety* and *Randomness* classification sets. Periphrases are often different to each other.

(1) The members of this curated group were not expected cumulate at the top of the list. The selection criteria was that there is *strong composition*. Therefore it is acceptable that for instance in the first column D4 (1a) and D6 (4a) appear at the lower end. Still we can see that the other curated members often fill the top of the list. We can assume that it is driven by the shear quantity of various Syntax Trees and Periphrases. We might infer some empirical agreement like "buildings made out of many smaller elements relate", even though the distinct building parts have quite different Periphrases.

(2) D2 - Expo 1967 Africa Group Pavilion (Montreal) performs well in the first column (2a), but performs weaker in third column (2c). Though the situation is not as negative. There is a huge gap in the empirical result between the first 4.5 and the second 3.4 ranking building (2c). The software can not simulate this. Still it also rates D2 at the second rank. The software might overrate the composition. It was challenging to create the classification data for D2 Africa Group Pavilion (2b). The recursive self similarity at the cluster as well at the building level required *twists*. We can interpret the twists as the freedom of a language to express things which have not been anticipated.

(3) B1 Soviet Union Pavilion as well as A3 Europe Pavilion are underrated by the software in the first column (3a) (3d). Both are modelled as single Periphrases. The common featureRidgeSingle / featureRidgeMultiple can not compensate for properties that the participants have discovered. In B1 and A3 the facets are modelled as texture, while in D1 Ontario Pavilion it is modelled in the Syntax Tree. This is a weakness and a statistical module with a "*seldom-combination-crossing-interface rule*" might help in future releases (see chapter 9.8.). This is similar to the way we can describe *cantilever* in multiple ways. Either as a tileViewFromBelow in a single Periphrase, or as a Syntax Tree branch with orientationVerticalDown plus sizeLargerSignificant. An alternative approach to allow *Weak References* across classification sets comes at a high technical complexity price.

(4) D6 - Expo 2010 Netherlands Pavilion (Shanghai) has the biggest Syntax Tree of all investigated pavilions. It was considered a very challenging building for the software, but it seems to perform quite acceptable (4a), (4b), (4c). Maybe we can take this as a hint that the Syntax Tree contributes positively.

B3 - Expo 1970 Philippines Pavilion (Osaka) is underrated by the software in the third column. The participants might have given the *spike* / *high point* more emphasis then the system is able to.

E

E1 - Expo 1967 Canada Host-Pavilion (Montreal)

Ø 10%

Ø 18%

picto	id	pic	emp	delta	calc
	E2		4.7	0% (1a)	4.7
	E5		3.7	25% (2a)	2.7
	E6		3.6	2%	3.5
	E4		2.9	11%	3.4
	E3		2.7	18%	2.0
	G1		2.5	39% (3a)	4.1
	E7		2.1	3%	2.3
	H1		1.6	33% (3d)	2.9
	F3		1.5	1%	1.5
	F2		1.5	18%	2.2
	G2		1.4	66% (3e)	4.0
	F1		1.3	0%	1.3

E2 - Expo 2010 China Host Pavilion (Shanghai)

Ø 16%

Ø 18%

id	pic	emp	delta	calc
E5		4.4	0%	4.4
E6		3.9	5%	3.7
E4		2.7	8%	3.1
E7		2.3	51% (1b)	4.4
H2		1.7	11%	1.2
H3		1.5	31% (1d)	2.8
F3		1.3	22%	2.1
F2		1.2	18%	1.9

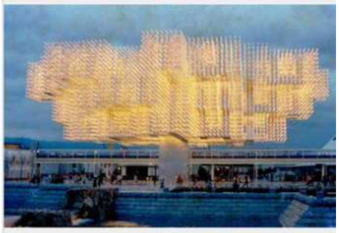
E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)

Ø 8%

Ø 11% (4c)

	id	pic	emp	delta	calc
P1	E4		3.4	0%	3.4
P2	E6		3.4	8%	3.0
P3	E5		2.9	4%	2.8
P4	E2		2.6	3% (1c)	2.7
P5	H3		1.9	18% (3c)	2.7
P6	E7		1.6	25%	2.6
P7	G2		1.6	1% (4d)	1.5
P8	F3		1.5	26% (3f)	2.6

E4 - Expo 2010 Saudi Arabia Pavilion (Shanghai)



E5 - Expo 1970 Switzerland Pavilion (Osaka)

E6 - Expo 1967 Quebec Region Pavilion (Montreal)

E7 - Expo 2010 South Korea Pavilion (Shanghai)

E

Cantilever

Table 26: Results of curated group E – Cantilever
Contains pavilions E1, E2, E3, E4, E5, E6, E7
Empirical data and calculated data for E1, E2, E3

12.1.5. E – Cantilever

Common characteristics: all members have a cantilever. It is well visible in all but E7 where the cantilever part is at a smaller level and mixed with other properties. When the angle at the top is acute like in E1, E2, E4 then featureRidgeMultiple is utilised. E1 does not have a Syntax Tree while E2 and E3 have.

We will first look at the first and second column and then dedicate two separate pages for the third column, which is about our canonical example the E3 Kaleidoscope Pavilion.

When we would exclude E7 Korea Pavilion (see Figures 311, 312, 355, 356 and 357), then the curated members perform acceptable. We will revisit E7 Korea Pavilion in the findings of this thesis as a building which is "not fitting the system" as it is *intended* to be complex by their creators. For this research project this is one of the most interesting groups; as in "Does cantilever matter?" and the empirical data supports a "Yes".

(1) E1-to-E2 (1a) has a small standard deviation of 0.51, which is rare for the top performing spot. E2 China Host Pavilion does well in the first (1a) and third column (1c). While it thrown back in its own second column by problematic E7 (1b) and H3 (1d).

(2) E5 - Expo 1970 Switzerland Pavilion (Osaka) performs poorly in the first column (2a) of E1 Canada Post Pavilion. The software is underrating it, while the participants identify strong similarity. The common cantilever was picked up by a good match of tiltWidenComplete and tiltWidenComplete via a *hasVeryStrongLink* in the Weak References. Tilt contributes 37% to the similarity, while textureFacetedRegular only 4%. This is mainly due to the fact that the Texture was added as *minor* in the classification data. We can speculate: either the participants saw much more value in the texture, or they rated the cantilever in their mind stronger then the software can do. Tilt is just one of ten slots in the Periphrase therefore it is watered down by the contribution from other slots; often from default classification items.

(3) Buildings from other curated groups perform quite unpredictable. They are often overrated by the software; in the first column G1 (3a), H1 (3d), G2 (3e); in the second column H3 (1d); in the third column H3 (3c) and F3 (3f).

E – Cantilever –E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)

(4) E3 - Expo 1967 Kaleidoscope Pavilion (Montreal) is our canonical example. And it works with 11% (4a) better then the other two columns. Especially for the peers in the curated group it has a good value of 8%. The weaker performance of the buildings from other curated groups is rooted in the behaviour of "Position 7 (4d) - G2 - Expo 2012 Hyundai Corporate Pavilion (Yeosu)". The reader might read it ahead.

(P1) Position 1 – E4 - Expo 2010 Saudi Arabia Pavilion (Shanghai) (see chapter 10.1 for additional photographs and analysis). It get its similarity contribution mainly from angleObtuse (21%), edgeSmooth (21%) and tiltViewFromBelow (19%) while curvatureConvexStraight only contributes 8%. We can observe that angleObtuse and edgeSmooth can compensate for the Curvature. 8% of the contribution come from the second Periphrase and 6% from the composition. When we compare E4 to the second and third position which mainly benefit from 90 degree angles, we can see that not always one or two classification sets dominate a ranked list.

(P2) Position 2 – E6 - Expo 1967 Quebec Region Pavilion (Montreal) (see chapter 10.2 for additional photographs and analysis). tiltViewFromBelow (27%) and proportionZeroZeroM2 (27%) together contribute over half of the similarity. Both are *direct matches* and are marked as *significant* in both trees.

(P3) Position 3 – E5 - Expo 1970 Switzerland Pavilion (Osaka). – The behaviour is similar to Position 2, though with a bit less contribution from the *Proportions* classifications set.

(P4) Position 4 – E2 - Expo 2010 China Host Pavilion (Shanghai) (see chapter 10.4 for additional photographs and analysis). The same values like in Position 2 and 3 are also at work, but in a weaker setup. textureStripedRegular helps to fill the gap.

(P5) Position 5 – H3 - Expo 2010 Australia Pavilion (Shanghai) (see also Figures 308, 309 and 310 further below). 6% of the similarity is contributed by the composition – especially from sizeSmallerSignificant – which seams acceptable. But there is a problem at a different level. When we inspect the Periphrase match in details we see that the cylinder of the E3 Kaleidoscope is actually matched against the spiral walkway of the H3 Australia Pavilion and not the wave like main building shape. This was decided by the software at the interface between Periphrases and Syntax Trees. The software permutes through all combination and even though the spiral is a secondary Periphrase it still wins the calculation mainly driven by its significant curvatureConvexStraight , tiltViewFromBelow and related edgeSmooth. We do not distinguish between wall and roof in the *Curvature* classification set. We pay the price for the simplicity of the strong independence. A context aware software feature could help, but would increase complexity.

(P6) Position 6 – E7 - Expo 2010 South Korea Pavilion (Shanghai) (see also Figures 311, 312, 355, 356 and 357). – As mentioned before: The behaviour of the E7 Korea Pavilion is hard to predict. It might be noted that there is a big flipped cylinder present in the E7, which leads to matches in the *Curvature* slot. A lot of contribution come from the default classification items for upright angles.

(P7) Position 7 - G2 - Expo 2012 Hyundai Corporate Pavilion (Yeosu) (see also Figures 313, 314, 315 and 316). It is indeed an unusual building. As we have seen in chapter 10, that the software collects “points” which are then remapped for the purpose of the comparison with the empirical data. The top performing building E4 collect 420 points, the seventh building in the calculated ranking F3 collects 240 points. While the G2 Hyundai Corporate Pavilion collects a stunning 9. This leads to a large gap which fuels the delta of the buildings at the bottom of the list. Therefore they are all highly overrated. We can see that H3 (P5), E7 (P6) and F3 (P8) are rated very similar by the participants. Also the calculated values for these three are close to each other. Would we exclude G2 Hyundai Corporate Pavilion from the system, they mean value would improve significantly.

(P8) Position 8 – F3 - Expo 2000 Japan Pavilion (Hannover). The explicit Periphrase slots are contributing not directly but rather via Weak References. Their values are lower because of the Weak Reference penalty.

Figure 308: H3 - Expo 2010 Australia Pavilion (Shanghai)


Figure 309: H3 - Expo 2010 Australia Pavilion (Shanghai)


Figure 310: H3 - Expo 2010 Australia Pavilion (Shanghai)


Figure 311: E7 - Expo 2010 South Korea Pavilion (Shanghai)


Figure 312: E7 - Expo 2010 South Korea Pavilion (Shanghai)


Figure 313: G2 - Expo 2012 Hyundai Corp. Pavilion (Yeosu)


Figure 314: G2 - Expo 2012 Hyundai Corp. Pavilion (Yeosu)


Figure 315: G2 - Expo 2012 Hyundai Corp. Pavilion (Yeosu)


Figure 316: G2 - Expo 2012 Hyundai Corp. Pavilion (Yeosu)

F

F1 - Expo 1970 Fuji Corporate Pavilion (Osaka)

Ø 9%

Ø 9%

picto	id	pic	emp	delta	calc
	F5		4.2	0% (2a)	4.2
	F3		3.8	2%	3.8
	F2		3.7	19% (3a)	3.0
	F7		3.5	11%	4.0
	F4		3.3	6%	3.1 (1a)
	F6		3.1	19%	2.4
	G2		1.9 (1d)	17%	2.5
	H1		1.8	3%	2.0
	G1		1.7	5%	1.9
	H2		1.6	15%	2.3
	G3		1.4	10%	1.8
	E1		1.2	0%	1.2

F

Blob

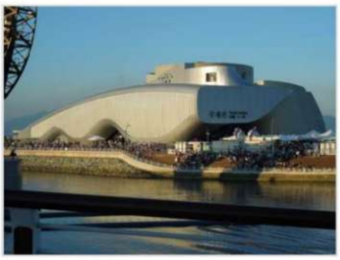
F2 - Expo 2010 Japan Pavilion (Shanghai)

Ø 5% (1b)

Ø 9%

id	pic	emp	delta	calc
F5		4.6	0% (2b)	4.6
F4		3.8	4%	4.0
F7		3.7	9%	4.0
F6		3.2	9% (4b)	2.9
E4		3.0	26% (5b)	4.1
E3		1.8	15%	2.4
G3		1.3	6%	1.6
G2		1.2	0%	1.2

F4 - Expo 2000 Hope Theme Pavilion (Hannover)



F6 - Expo 2012 Ocean Coast Pavilion (Yeosu)

F3 - Expo 2000 Japan Pavilion (Hannover)

Ø 12%

Ø 9%

id	pic	emp	delta	calc
F5		4.0	4% (2c)	3.8
F4		3.6	9%	3.2
F2		3.4	14% (3c)	2.8
F6		3.4	3%	3.5
F7		2.7	31%	4.0
H2		1.7	2%	1.6
G3		1.7	12%	2.1
E5		1.2	0%	1.2

F5 - Expo 2010 Aviation Pavilion (Shanghai)

F7 - Expo 1970 Gas Corporate Pavilion (Osaka)

Table 27: Results of curated group F – Blob
Contains pavilions F1, F2, F3, F4, F5, F6, F7
Empirical data and calculated data for F1, F2, F3

12.1.6. F – Blob

Common characteristics: This group contains members which are often described as *blobs* or *free from* buildings in literature. They have non-rectangular *Angle-Plane* as well as *Angle-View* and edgeSmooth. Nearly all have a *Curvature* slot marked as significant. Sometimes multiple *Curvature* values are present. They all utilise *Tilt*. Generally speaking they contain Periphrases with a lot explicit values, as their building shapes are quite apart from the default *perfect cube*.

(1) The curated group performs well in all three columns. There is even a significant gap between F6 at position 6 and G2 at position 7 in the first column (1d) in the empirical data. While the software has problem with F6, the gap is present at F4 (1a) in the calculated data. The very good value of 5% (1b) for the curated group in the second column is due to the fact that the software matches the big gap between the first and the second, similar to the empirical data. In the first (2a) and the second column (2b) we have at top and bottom a delta of 0%. Also the bottom value in the third colum is a 0%. This leads to a better overall mapping. It is a positive indication that the software can match important empirical reference points.

(2) F5 - Expo 2010 Aviation Pavilion (Shanghai) is at the top of all three columns (2a), (2b), (2c). It might be the stereotypical *blob*. Though it does have a Syntax Tree for the smaller mushroom and dome at its ends (see Figures 348, 348 and 350). In the second column (2b) the Syntax Tree helps with 5% contribution mainly from the sizeSmaller and sizeSmallerSignificant.

(3) F2 - Expo 2010 Japan Pavilion (Shanghai) does not perform well in the first (3a) and third column (3c). It does not have an anticlastic curvatureConcaveConvex which is important in F1 and F3. F1 and F3 do have a second synclastic curvatureConvexConvex but only at minor or normal significance.

(5) E4 - Expo 2010 Saudi Arabia Pavilion (Shanghai) is the obvious outlier in the second column (5b) . An important contributor to the similarity of F2-to-E2 is edgeSmooth in viewEdge. This items alone can not express the cutaway of the roof. The featureRidgeSingle which is present in E2 does not matter in the F2-to-E2 pair as it contributes nothing. One solution in future revisions might be to assign a penalty in a pair if one side contains a significant value and the other one does not have something corresponding. A general disadvantage might be exposed here, as we do not model the roof explicitly in the proposed system.

E3 - Expo 1967 Kaleidoscope Pavilion (Montreal) would improve in the second column, when we would drop minor Periphrases (see chapter 12.4), from a delta of 17% to 7%. The Syntax Tree with branches matching the E3 base and the F2 annex building are the source of the overrating.

G

G1 - Expo 1967 Soviet Union Pavilion (Montreal)

Ø 5%

Ø 7%

picto	id	pic	emp	delta	calc
	G5		4.5	0% 1a	4.5
	G3		4.1	0% 3a	4.1
	G7		3.9	9%	3.5
	G6		3.8	14%	3.2
	E1		2.3	6%	2.1
	G2		2.3	5%	2.1
	G4		2.1	0%	2.1
	E2		2.0	35% 2a	3.4
	H1		1.6	3%	1.7
	F1		1.6	2%	1.7
	H3		1.5	12%	2.0
	H2		1.4	0%	1.4

G2 - Expo 2012 Hyundai Corporate Pavilion (Yeosu)

Ø 5%

Ø 8% 5b

id	pic	emp	delta	calc
H2		2.3 5d	17%	1.6
H3		2.3	21%	1.4
F3		2.2	7%	2.0
G6		2.2	7%	1.9
G7		2.1	2%	2.0
G4		2.1	7%	2.3
G5		2.0	4%	2.1
E2		1.4 5e	4%	1.6

G3 - Expo 2000 Germany Host Pavilion (Hannover)

Ø 14%

Ø 18%

id	pic	emp	delta	calc
G5		3.7	0%	3.7
G6		3.3	5%	3.5
G7		2.9	11%	3.3
G4		2.8	33% 4c	1.5
G2		1.9	19%	1.2
E2		1.9	40% 2c	3.5
H3		1.6	8%	1.9
E3		1.2	26%	2.2

G4 - Expo 2010 Brazil Pavilion (Shanghai)

G5 - Expo 1967 Italy Pavilion (Montreal)

G

Concave

G6 - Expo 1998 Portugal Host Pavilion (Lisboa)

G7 - Expo 1970 Textiles Corporate Pavilion (Osaka)

Table 28: Results of curated group G – Concave
Contains pavilions G1, G2, G3, G4, G5, G6, G7
Empirical data and calculated data for G1, G2, G3

12.1.7. G – Concave

Common characteristics: This group is modelled to test curvatureConcaveStraight. It is also a test for the decision to not distinguish between walls and roofs. While this conceptual decision works well for group F, it is more challenging in group G. G1 has a concave roof, G2 has concave roof and walls, while G3 has only concave walls.

(1) The curated groups perform differently in each column. The first column is the best column with twelve buildings in the whole setup. Its mean delta is a 7.7% (1a), and even only 5.0% (1a) within the curated group. We have a delta of 0% four times across the table. The gap between position 1 and 2 (1a) is matched exactly by the software.

(2) E2 - Expo 2010 China Host Pavilion (Shanghai) is the obvious outlier in the first column (2a). The significant overrating by the software comes from two source: similar Periphrases and a similar Syntax Tree structure. The first similar Periphrase pair is the G1-Roof and the E2-upside-down pyramid, which contributes 60% of the similarity. But the second Periphrase is the G1-Hall and the four E2-Feet. As simple blocks they have a lot of default values in common, this leads to 12% contribution, which is questionable. Both buildings are modelled as a stack of three distinct building shapes. One Syntax Tree branch is of *normal* significance. Therefore it contributes 35% to the similarity. The composition in this branch has *direct matches* in *all* its slots: spacingContactPartial, card2, orientationVerticalDown, sizeSmaller. But when we inspect E2 we will see that these direct matches come from different branches. This is a weakness of the *strong independence assumption* and similar to the problem discussed in 9.2. The situation is similar in third column (2c).

(3) G3 - Expo 2000 Germany Host Pavilion (Hannover) performs well in the first column (3a). But this is not due to a common curvatureConcaveStraight but rather the setup of the expressive roofs. Items like orientationVerticalDown and sizeSmallerSlightly contribute in the Syntax Tree match.

(4) G3 - Expo 2000 Germany Host Pavilion (Hannover) has concave glass walls. In its own third column it works well with G5, G6, G7, but poorly with G4 (4c). Even though G4 - Expo 2010 Brazil Pavilion (Shanghai) also has concave walls, it is underrated by the software. One a first look it all went accordingly. G4 is matching the walls rather then the roof. This is thanks to the interface permutations. Though unfortunately the combined effect of *rules of significance* and *rule of composition present* reduce the value by 55%. As a consequence it can not keep up with the empirical data.

(5) G2 - Expo 2012 Hyundai Corporate Pavilion (Yeosu) is discussed a few pages further below as we ran out of print page space.

H

H1 - Expo 2010 Chile Pavilion (Shanghai)

Ø 6% 3a
Ø 14%

picto	id	pic	emp	delta	calc
	H3		4.6	0% 1a	4.6
	H4		4.4	12%	3.9
	H2		4.1	3%	4.0
	H5		3.4	1%	3.5
	E3		2.7	17% 2a	3.4
	H7		2.6	11%	2.2
	H6		2.3	8% 4a	2.6
	F1		1.9	20% 2d	2.7
	F2		1.7	30% 2e	3.0
	G1		1.5	22%	2.3
	E2		1.3	38%	2.8
	E1		1.3	0%	1.3

H2 - Expo 2010 Info Communication Corporate Pavilion (Shangh

Ø 7%
Ø 8%

id	pic	emp	delta	calc
H4		3.8	4%	3.6
H5		3.3	10%	3.8
E3		2.6	17% 2b	3.3
H7		2.3	11%	1.9
F2		2.2	6%	2.4
H6		1.9	3% 4b	2.0
G4		1.8	9%	2.2
G3		1.4	0%	1.4

H3 - Expo 2010 Australia Pavilion (Shanghai)

Ø 4% 5c
Ø 6%

id	pic	emp	delta	calc
H4		4.1	0% 1c	4.1
H2		3.7	9%	4.0
H5		3.6	7%	3.9
F3		2.5	4%	2.6
H6		2.2	2% 4c	2.2
H7		2.1	0%	2.1
F2		1.5	27% 5d	2.6
G5		1.4	0%	1.4

H4 - Expo 2010 Private Enterprise Corporate Pavilion (Shanghai)

H5 - Expo 2010 Spain Pavilion (Shanghai)

H6 - Expo 1992 Palaza Del Futuro Theme Pavilion (Sevilla)

H7 - Expo 2000 Hungary Pavilion (Hannover)

H
Undulation

Table 29: Results of curated group H – Undulation
Contains pavilions H1, H2, H3, H4, H5, H6, H7
Empirical data and calculated data for H1, H2, H3

12.1.8. H – Undulation

Common characteristics: This group is modelled to test curvatureUndulationWaves and curvatureUndulation. On the first five buildings curvatureUndulationWaves appears in the walls. These five also have in their plane angleObtuse, edgeSmooth and tiltApproximatelyNone in common. The last members are different: they only contain curvatureUndulation and it happens either on the roof or in a different direction on the wall.

(1) The Curated members perform well, but we can observe that E3, F2 and F3 from other groups are sneaking into the top of the tables. They are overtaking H6 and H7. We get the top value correct on two (1a) (1c) columns. We always gets the bottom value right.

(2) E3 - Expo 1967 Kaleidoscope Pavilion (Montreal) is overrated in the first (2a) and second column (2b). This is not due to its Syntax Tree. It is also not due to curvatureConvexStraight, as it does have no Weak Relationship with curvatureUndulation. It is rather caused by the direct matches on the significant angleObtuse and edgeSmooth. The matches on *Angle* and *Edge* are expected. The conceptual idea is that the missing *Curvature* match would be enough to correctly place the pair. This does not work out. In future research a setup might follow a paraphrased "All classification sets are equal, but some classification sets are more equal then others". Maybe *Curvature* should be pushed and *Angle* and *Edge* which are often correlated reduced. The overrating of the Kaleidoscope in the second column (2b) can be argued in a similar way. Also the overrating of F1 (2d) and F2 (2e) in the first column.

(3) H1 – Expo 2010 Chile Pavilion (Shanghai). The first column works very well on its curated members with a value of 6% (3a). But especially in the last third of the list there are many outlier. They are all overrated. This might very well be due to the composition of the blocks in H1. They have a very different shape and as *blocks* utilise a lot of defaults. In an experimental "drop of all minor compositions" (see chapter 12.4.2) we can see that this columns changes from a 14.5% to a 11.6%. The gain of 2.9% is the highest in the experiment. F2, G1, E2 all have Syntax Trees and secondary Periphrases.

(4) H6 - Expo 1992 Palaza Del Futuro Theme Pavilion (Sevilla) has undulation at the roof, while H1, H2, H3 all have them in the walls. H6 always appears in the middle of the result lists (4a), (4b), (4c). This is true for the empirical side as well as the calculated side. We can argue that the absence of a roof wall distinctions works. The undulation is reliable contributing 17% in first column (4a), 28% in second (4b) and 18% in third column (4c).

(5) H3 - Expo 2010 Australia Pavilion (Shanghai) is with 5.8% (5c) and 3.8% (5c) one of the best performing results. It has a single outlier: F2 (5d). Additional to the "undulating wall" classification items, the common latticeNoise and latticeStrechUnproportional help to order the curated members in the correct way.

Supplement for group G (we ran out of print page space)

(5) G2 - Expo 2012 Hyundai Corporate Pavilion (Yeosu) is indeed an unusual building. It was added to the group because it had both a concave roof, as well as concave walls. The other building shape properties are also very unusual. See Figures 313, 314, 315 and 316 from the E3 Kaleidoscope page. The remapping starts at an empirical 2.3 (5d) and then the empirical data is very dense, just the last building drops to 1.4 (5e). So the 8% (5b) overall score must be taken with a grain of salt. The participants see more similarities with undulating buildings like H2, H3, or the blob F3 then with the curated peers. These other buildings are also utilising Curvature and related classification sets like Angle and Edge.

12.1.9. Groups S to Z

The next eight groups S, T, U, V, W, X, Y, Z are shorter and the findings are more of an indicative nature, as only the first building has enough data. They are more explorations if a topic is worth to pursue. Though the drivers for the curation might be interesting. The empirical setup is organised in a way, that would allow to lift these eight curated groups to the same level like A, B, C, D, E, F, G H. This can happen without requiring to touch A to H again.

Because we only have three buildings per curated group, the "common characteristics" are broader then in more diverse curated groups with seven members. Therefore we see some detailed enumeration of classification items at the beginning. Except for group S.

There is no Truncation classification set. It is deliberately skipped as discussed in chapter 6.4.2. The curated groups S and T test how shapes which are related to truncation can be modelled.

S

S1 - Expo 2010 France Pavilion (Shanghai)

Ø 10%

Ø 7%

picto	id	pic	emp	delta	calc
	T1		4.0	0%	4.0
	S3		3.4	18%	2.7
	U1		3.0	10%	2.6
	S2		2.5	3%	2.6
	Y1		2.5	9%	2.8
	C1		2.0	12%	1.5
	G1		1.8	2%	1.9
	V1		1.5	1%	1.6

S2 - Expo 2010 Finland Pavilion (Shanghai)

id	pic	emp	delta	calc
X2		3.6	0%	3.6
G2		2.0	2%	1.9
B2		1.4	18%	2.1
U2		1.3	0%	1.3

S

Truncation Hole

S3 - Expo 1967 Czechoslovakia Pavilion (Montreal)

id	pic	emp	delta	calc
H3		2.5	0%	2.5
V3		1.7	13%	2.2
B3		1.4	2%	1.4
X3		1.4	16%	2.0

Table 30: Results of curated group S – Truncation Hole
Contains pavilions S1, S2, S3
Empirical data and calculated data for S1

S – Truncation Hole

Common characteristics: This group is modelled to test featureLowpointCourt (Figure 187j) as a special case of a *low point*.

S2 - Expo 2010 Finland Pavilion (Shanghai) has a different outer building shape. featureLowpointCourt contributes 38% of the similarity. The empirical data as well as the calculate data place it in the middle of the result list. The delta is only 4%. Though the empirical data has a high standard deviation of 1.21.

S3 - Expo 1967 Czechoslovakia Pavilion (Montreal) is 18% off, but correctly placed at the second position. It gets 28% of it similarity from featureLowpointCourt.

Without the significant contribution of featureLowpointCourt the two curated peers would be strongly underrated.

T

T1 - Expo 2012 Samsunung Corporate Pavilion (Yeosu)

T2 - Expo 2010 Oil Corporate Pavilion (Shanghai)

T3 - Expo 2012 Posco Corporate Pavilion (Yeosu)

Ø 5%

Ø 7%

picto	id	pic	emp	delta	calc
	T3		4.1	0%	4.1
	S1		3.8	7%	3.5
	T2		3.7	9%	3.3
	H1		2.6	1%	2.7
	V1		2.3	8%	2.0
	U1		1.8	13%	2.3
	Z1		1.6	15%	2.2
	D1		1.4	0%	1.4

id	pic	emp	delta	calc
A2		2.8	12%	2.3
H2		2.6	7%	2.8
V2		1.7	8%	2.0
W2		1.6	0%	1.6

id	pic	emp	delta	calc
Y3		3.3	0%	3.3
S3		3.3	44%	1.5
E3		1.5	4%	1.3
C3		1.3	2%	1.4

T

Truncation Corner

Table 31: Results of curated group T – Truncation Corner
Contains pavilions T1, T2, T3
Empirical data and calculated data for T1

T – Truncation Corner

Common characteristics: The missing of a Truncation classification set, is compensated in this group by utilising multiple values per slot. We model the upright wall as well as truncated corner as pairs : anglePerpendicularApproximatly, angleObtuse, tiltApproximatelyNone, tiltWiden.

T3 - Expo 2012 Posco Corporate Pavilion (Yeosu) it the obvious top performer. This is not only driven by the truncated corner but also by the significant matches on edgeFillet. The similar proportionZeroZeroM1 also contributes to the high similarity.

T2 - Expo 2010 Oil Corporate Pavilion (Shanghai) performs good.

U

U1 - Expo 1967 Netherlands Pavilion (Montreal)

Ø 6%

Ø 14%

picto	id	pic	emp	delta	calc
	U2		3.8	8%	3.5
	U3		3.6	5%	3.8
	S1		3.5	46%	1.7
	A1		2.4	25%	1.4
	V1		2.0	20%	2.8
	T1		1.9	5%	1.7
	E1		1.8	7%	1.5
	W1		1.2	0%	1.2

U2 - Expo 2010 Hamburg Urban Pavilion (Shanghai)

id	pic	emp	delta	calc
C2		3.6	0%	3.6
T2		2.9	26%	1.9
Y2		1.3	3%	1.2
F2		1.2	22%	2.1

U

Penetrate Boxes

U3 - Expo 1970 Netherlands Pavilion (Osaka)

id	pic	emp	delta	calc
T3		2.7	30%	1.5
D3		1.6	27%	2.7
Z3		1.6	5%	1.8
F3		1.4	0%	1.4

Table 32: Results of curated group U – Penetrating Boxes
Contains pavilions U1, U2, U3
Empirical data and calculated data for U1

U – Penetrating Boxes

Common characteristics: Syntax Trees and Periphrases hardly deviate from the defaults. They do mainly on *Proportions* and tiltViewFromBelow. The penetrating boxes are modelled in the composition: spacingPlanarOverlapPartial, Cardinalities of more then card2, varietyMinor, randomMinor. The branches are of significance: *significant*, therefore contributions from the branches get low penalties.

U2: first Periphrase: 36%, second Periphrase 30%, composition: 33%
U3: first Periphrase: 31%, second Periphrase 37% , composition: 31%

The setup works well for the curated members. These are really different numbers then everywhere else. Usually the first Periphrase dominates. Though it is more challenging for the underrated S1 and S2 because they consist of only one Periphrase.

V

V1 - Expo 1967 Austria Pavilion (Montreal)

Ø 0%

Ø 7%

picto	id	pic	emp	delta	calc
	V3		3.6	0%	3.6
	X1		3.3	22%	2.4
	V2		3.0	0%	3.0
	B1		2.3	17%	1.6
	U1		2.0	5%	2.2
	T1		1.6	2%	1.5
	S1		1.6	9%	1.2
	F1		1.2	4%	1.4

V2 - Expo 1970 Italy Pavilion (Osaka)

id	pic	emp	delta	calc
D2		2.8	0%	2.8
E2		2.2	3%	2.1
Z2		2.2	24%	1.2
S2		1.2	0%	1.2

V

Geometry

V3 - Expo 1967 Man The Explorer Theme Pavilion (Montreal)

id	pic	emp	delta	calc
A3		3.2	36%	1.8
U3		1.9	3%	2.0
G3		1.6	42%	3.2
W3		1.3	0%	1.3

Table 33: Results of curated group V
Contains pavilions V1, V2, V3
Empirical data and calculated data for V1

V – Geometry

Common characteristics: The members have a strong *geometrical* appearance which constitutes itself in clean 60 and 45 degree angles. This is modelled with angleApproximately60 and angleApproximately45. Also two opposing Tilt values are present, like tiltTaper and tiltWidenSignificant.

V2 - Expo 1970 Italy Pavilion (Osaka), additionally benefits from curvaturePlanarZigZag and latticeNoise.

V3 - Expo 1967 Explorer Theme Pav. (Montreal) benefits from textureFacetedRegular.

X1 - Expo 2010 Tours Pavilion (Shanghai) has a surprising high empirical value. Maybe the participants emphasised colour and pattern? The calculated value with textureFacetedRegular, and Weak References on *Tilt* and *Angle-View* are within the expectations.

W

W1 - Expo 2010 Expo Culture Center Host Pavilion (Shanghai)

Ø 5%

Ø 23%

W2 - Expo 2010 Singapore Pavilion (Shanghai)

W3 - Expo 1998 Pavilion Of The Future Theme Pavilion (Lisboa)

picto	id	pic	emp	delta	calc
	W3		4.9	0%	4.9
	W2		3.8	9%	4.1
	Y1		3.3	22%	4.2
	T1		2.4	16%	3.0
	X1		2.3	18%	3.0
	F1		1.5	80%	4.7
	Z1		1.5	40%	3.1
	C1		1.3	0%	1.3

id	pic	emp	delta	calc
Y2		4.4	0%	4.4
H2		2.9	2%	3.0
V2		1.4	5%	1.2
C2		1.2	0%	1.2

id	pic	emp	delta	calc
C3		3.3	0%	3.3
Y3		2.5	24%	1.6
G3		1.6	15%	2.2
U3		1.1	0%	1.1

W

Ufo

Table 34: Results of curated group W – Ufo
Contains pavilions W1, W2, W3 – Empirical data and calculated data for W1

W – Ufo

Common characteristics: angleObtuse, edgeSmooth (significant) in view and plane, also edgeSharp together with featureRidgeSingle and two Tilt values like: tiltWiden, tiltTaper.

It works well for the curated members but problematic afterwards. W3 is with 4.9 the highest empirical value. Its also the second lowest standard deviation 0.41.

Problem one: C1 has such a low calculated value that causes a huge gap. The other lower positions are pushed into overrating. This is similar to E3-to-G2. When this would behave differently, then the lower part would be less dramatic.

Problem two: There are many explicit slots filled in the single Periphrase. This causes false positives from other buildings. Especially when they also have multiple values in slots like *Tilt*, for instance F1 - Expo 1970 Fuji Corporate Pavilion (Osaka). F1 also has a round ground plane which contribute high values.

X

X1 - Expo 2010 Innovative Tours Theme Pavilion (Shanghai)

Ø 2%

Ø 9%

picto	id	pic	emp	delta	calc
	X3		4.9	0%	4.9
	D1		2.8	4%	2.6
	X2		2.8	4%	2.6
	Z1		2.7	32%	1.5
	W1		2.3	16%	1.6
	Y1		1.8	13%	1.3
	S1		1.4	4%	1.3
	E1		1.2	0%	1.2

X2 - Expo 1967 Brewers Pavilion (Montreal)

id	pic	emp	delta	calc
D2		2.1	4%	2.0
Z2		2.0	17%	1.3
G2		1.7	11%	1.2
U2		1.2	23%	2.1

X

Bubbles

X3 - Expo 1970 France Pavilion (Osaka)

id	pic	emp	delta	calc
V3		3.0	0%	3.0
Z3		2.5	9%	2.2
H3		2.0	3%	1.9
D3		1.7	0%	1.7

Table 35: Results of curated group X – Bubbles
Contains pavilions X1, X2, X3 – Empirical data and calculated data for X1

X – Bubbles

Common characteristics: The domes are modelled with curvatureConvexConvex accompanied with angleObtuse. tiltTaper is utilised everywhere. Self-similarity, by providing nearly identical Periphrases into a branch with significance *significant* works well. The composition utilises spacingPlanarOverlapPartial, cardApproximatly5. sizeSmaller with randomSome or randomSignificant, as well as varietyNone or varietyMinor which are connected via Weak References.

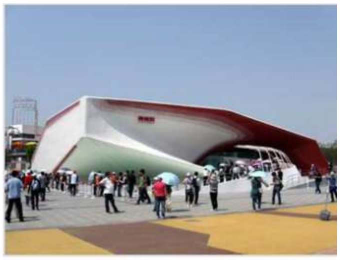
X3 - Expo 1970 France Pavilion (Osaka) is the second highest empirical match, with the lowest standard deviation. It gets 1429 points by the software while the second best is at 626 points. This causes a big gap of 1.1, but this matches well with the empirical data.

Z1 - Expo 1967 Germany Pavilion (Montreal) is the outlier. It is surprising that it is underrated.

Y

Y1 - Expo 2010 Denmark Pavilion (Shanghai)

Y2 - Expo 2010 General Motors Corporate Pavilion (Shanghai)



Y3 - Expo 2010 Austria Pavilion (Shanghai)

Ø 0%

Ø 6%

picto	id	pic	emp	delta	calc
	Y2		4.7	0%	4.7
	W1		3.3	3%	3.4
	Y3		2.7	0%	2.7
	X1		2.4	12%	1.9
	B1		2.2	4%	2.0
	G1		1.6	5%	1.8
	Z1		1.4	20%	2.2
	U1		1.3	0%	1.3

id	pic	emp	delta	calc
S2		4.3	0%	4.3
X2		3.8	34%	2.4
E2		1.4	5%	1.2
B2		1.2	8%	1.5

id	pic	emp	delta	calc
A3		3.3	0%	3.3
W3		2.6	2%	2.5
S3		2.1	5%	2.3
E3		1.8	0%	1.8

Y

Spiral

Table 36: Results of curated group Y – Spiral
Contains pavilions Y1, Y2, Y3
Empirical data and calculated data for Y1

Y – Spiral

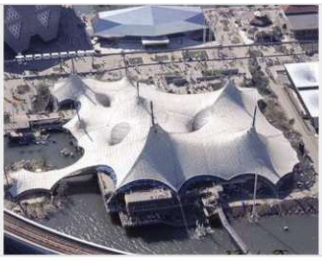
Common characteristics: featureSpiral is defined as a member of the *Feature* set (see chapter 7.3.6). Spirals are often round which leads to significant angleObtuse and edgeSmooth in the plane. Walls are still upright with curvatureConvexStraight. Spirals have often compact proportion like proportionZeroZeroM1. LatticeTwist is a similar concept to featureSpiral and present everywhere. In Y3 the spiral is hidden, but visible in aerial.

Y2 - Expo 2010 General Motors Pavilion (Shanghai) is as expected the top similarity. Also the margin to the second place is similar in the empirical as well as calculated data.

Y3 - Expo 2010 Austria Pavilion (Shanghai) is located in the middle in the empirical as well as the calculated column. FeatureLowpointCourt contributes 16% to the similarity.

Z1 - Expo 1967 Germany Pavilion is the outlier. It is surprising that it is overrated.

Z



Z1 - Expo 1967 Germany Pavilion (Montreal)

Ø 1%

Ø 11%

picto	id	pic	emp	delta	calc
	Z2		4.5	0%	4.5
	Z3		3.8	2%	3.9
	V1		3.6	33%	2.3
	X1		2.4	18%	1.6
	A1		2.0	20%	2.8
	H1		1.8	8%	1.5
	W1		1.8	7%	2.1
	Y1		1.5	4%	1.6

Z2 - Expo 2010 Norway Pavilion (Shanghai)

id	pic	emp	delta	calc
A2		3.2	0%	3.2
T2		2.0	20%	2.8
W2		1.6	5%	1.4
F2		1.4	35%	2.8

Z

Anticlastic

Z3 - Expo 1970 elecommunication Corporate Pavilion (Osaka)

id	pic	emp	delta	calc
X3		2.4	16%	1.8
F3		2.1	2%	2.2
B3		2.1	10%	2.4
T3		1.3	0%	1.3

Table 37: Results of curated group Z – Anticlastic
Contains pavilions Z1, Z2, Z3
Empirical data and calculated data for Z1

Z – Anticlastic

Common characteristics: The group was modelled to see if curvatureConcaveConvex together with featureHighpointMultiple, featureLowpointMultiple and featureRidge-Multiple is a valid way to model "form active" buildings with nets or membranes. There are additional common slots in anglePerpendicularOffSignificantly and latticeNoise.

Z2 and Z3 are in the top spots. The empirical gap is well matched by the software.

V1 - Expo 1967 Austria Pavilion (Montreal) is the biggest outlier. The empirical data is surprising.

"Form active" buildings that use membranes or nets, have a distinct shape language which connects them to their peers. They seem to be more challenging to be compared with other building shapes.

This page intentionally left blank

12.2. Results of Conceptual Features

In the previous section we looked at the results for curated groups. This section will refocus from pavilion groups to the theoretical concepts. There are four distinct classification concepts introduced in this thesis[239]. This section will discuss the positive impact that each concept contributes. To give the reader some context we will show the whole conceptual system again in Figure 317. Next to it in Figure 318 we describe five parts that we will turn on and off.

The section will follow the outline: Discuss the aggregated result; discuss the result of the canonical example Kaleidoscope; show various visualisations of the main result table and single out interesting examples.

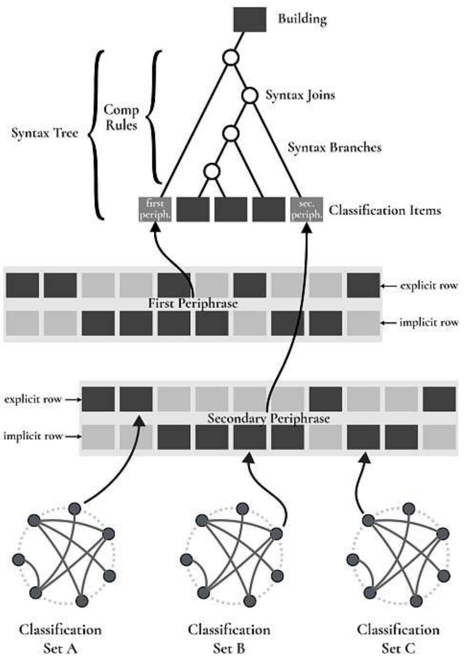


Figure 317: Overview of the concepts introduced in this thesis. See Figure 60 for a bigger version of this diagram

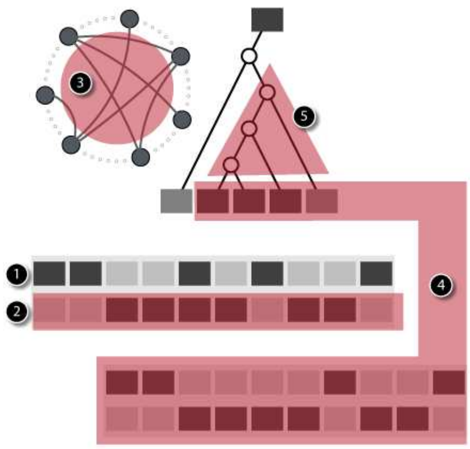


Figure 318: Overview of concepts that can be turned on and off.
(1) firstOnly – explicit items assigned by a person
(2) firstDefaults – implicit items added by the software
(3) firstDefRef – named relationships within one set
(4) withSec – further secondary periphrases connected via a syntax tree
(5) normal – rules within a syntax tree that alter values

239 Classification Sets, Weak References, Periphrases, Syntax Trees.

The following list describes the the numeric columns[240] in Figure 319 from right to left. This reverse order is easier to follow because concepts are *added* but rather *subtracted*[241]:

- *zero* – The reference value as discussed in the introduction of chapter 12.
- *firstOnly* – Only the first Periphrase is considered, and only the explicitly assigned slots. This correspond to (1) in Figure 318.
  (*firstOnly* is an abbreviation for: First Periphrase Only)
  (Alternative title: Periphrase explicit)
- *firstDefaults* – Everything from *firstOnly* plus the implicit default items that contribute to the perfect cube. This correspond to (1) and (2) in Figure 318.
  (*firstDefaults* is an abbreviation for: First Periphrase and Default Items)
  (Alternative title: Periphrase implicit)
- *firstDefRef* – Everything from *firstDefaults* plus the *Weak References* from chapter 9.3 that connect various items within one classification set. This correspond to (1), (2) and (3) in Figure 318.
  (*firstDefRef* is an abbreviation for: First Periphrase, Default Items and References)
  (Alternative title: Weak References)
- *withSec* – Everything from *firstDefRef* plus any secondary or tertiary Periphrase that makes up a composition. When a Syntax Tree is present then the Syntax Tree specific classification items are includes. This correspond to (1), (2), (3) and (4) in Figure 318.
  (*withSec* is an abbreviation for: With Secondary Periphrases)
  (Alternative title: Syntax Tree)
- *normal*. Everything from *withSec* plus the rules discussed in chapter 9.7. The rules govern how values bubble up through the Syntax Tree. For instance if branches are considered *significant*. This is the full fledged classification system introduced in this thesis. This correspond to (1), (2), (3), (4) and (5) in Figure 318.
  (Alternative title for *normal*: Rules)

240 The terms "firstOnly, firstDefaults, firstDefRef and withSec" are technical variables names, which represent a selection from a broader range of variations available in the software implementation. The following bullet list will try to explain them, and also provides less technical alternative titles.

241 Later tables follow the same pattern.

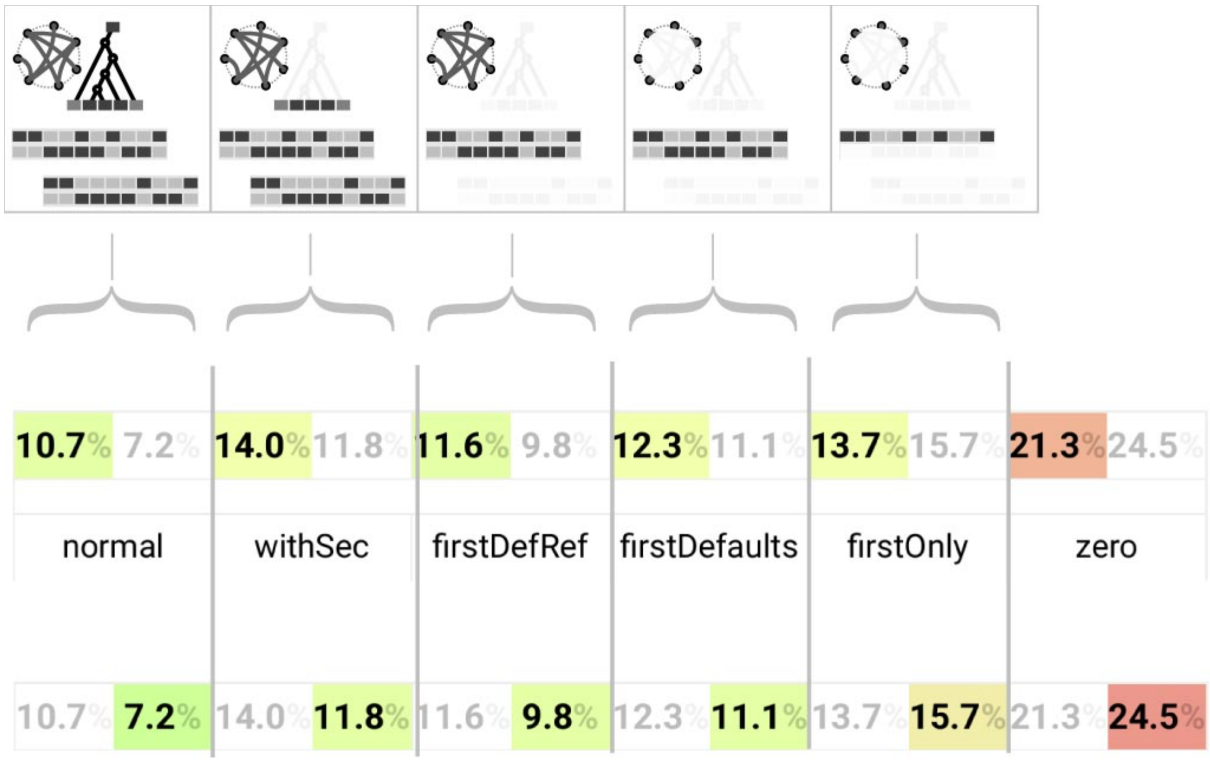


Figure 319: Turning conceptual features on and off. Aggregated results of all 32 pavilions. Top row numbers with the coloured background are the main results.

12.2.1. Aggregated Results

Figure 317 shows the aggregated results for the 32 pavilions that have sufficient data. We discuss the results in the reverse order from right to left. The top numerical row contains the main result in the cells with the background colour. Similar to the previous section, the numbers represent the delta between *empirical data* and *calculated data*. Therefore the smaller the number the better the match.

- *firstOnly* - We see a significant difference between the 21.3% in the reference *zero* column and the 13.7% in the *firstOnly* column. We can interpret this as: A little bit of classification goes a long way.
- *firstDefaults* - We see a positive trend towards 12.3% compared to *firstOnly*. The default values are the bulk of classification data when we have a building shape which is similar to a cube. This is not an uncommon case. The default values assist the person creating the classification for a building to have convenient defaults and do less repetitive work.
- *firstDefRef* - The positive trend continuous to 11.6% as we make the classification sets smarter with *weak references*. The *weak references* lift the burden for the person creating the classification to pick one classification item over an other and fear that matches from neighbouring partly related classification items will have no effect.
- *withSec* - We see a negative impact to 14.0% when we include secondary distinct building parts, when we honour the fact that there is composition of building

shapes. In some cases the secondary distinct building part speaks a different design language. Imagine a blob like building with a cube annex part; for instance "F2 - Expo 2010 Japan Pavilion (Shanghai)".[242] Suddenly the dominating blob related classification items are mixed with cube related classification item. At this point there is no mechanism in place to give different significance. It is a mixed bag of classification items.

- *normal* - With the addition of rules that alter the value of a classification item regarding to its position in the Syntax Tree, the negative effect in *withSec* is compensated. We arrive at 10.7%.

We can see that the whole system performs with 10.7% compared to the 13.7% of the *onlyFirst* column; the "A little bit of classification goes a long way" column. The delta is just 3.6%. Of course this is connected to the definition of the maximum 100%.

- When we use the 21.3% value of the *zero* column as the maximum, then the improvement of *normal* over *zero* is about 49%. The improvement of *normal* over *onlyFirst* is 14%.
- When we use the 14.3% value from the *onlyFirst* column at the maximum, then the improvement of *normal* over *firstOnly* is about 25%

The bottom row in Figure 319 contains the result when only the sibling buildings of a curated group are taken into account. It follows similar trends like the just discussed full system. The results are generally better, but this can be attributed to the "curation" where alike or conceptually related buildings have been grouped and compared.

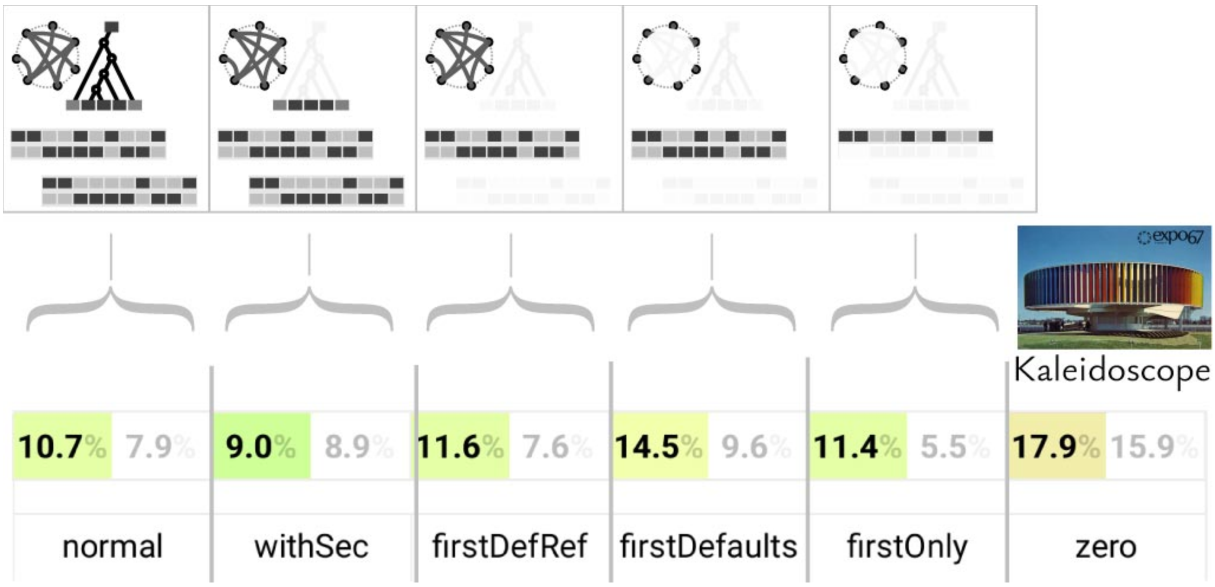


Figure 320: Turning conceptual features on and off. Results for the Kaleidoscope pavilion.

242 See photograph in Figure 238. Additional photographs are in Appendix A (19.1)

12.2.2. Kaleidoscope Result

Next we look at the detailed results of our canonical example; the Kaleidoscope. When we read the results in the reverse order from right to left we can observe:

- *firstOnly* - Because the Kaleidoscope has a clear geometrical shape of a cylinder the explicit items of the first Periphrase already give a good result of 11.4%. The value is nearly as good as the final value in the *normal* column which is at 10.7%.
- *firstDefaults* - Once we add the default values for the first Periphrase we get a negative impact to 14.5%. This is due to the fact that the distinct values from *firstOnly* are now associate with more generic values from the implicit default slots. More buildings that have very few in common with the cylinder are now considered. For instant cube like buildings with upright walls now have something in common with the Kaleidoscope.
- *firstDefRef* - The result improves again to 11.6% when the *Weak References* are activated. This is due to the fact that neighbouring smooth curvatures and obtuse angles get additional matches.
- *withSec* - Enables the secondary Periphrase of the Kaleidoscope: the small base. Because the small base is also classified as a “kind of cylinder” we have additional matches. Every positive match for the main cylinder is repeated with the small base. The impact is observable, because there are no Syntax Tree *rules* that would dim the scores of the unimportant small base. The 9.0% is the best result in the data row.
- *normal* - The main addition are the Syntax Tree rules. They significantly reduce the scores from the unimportant base of the Kaleidoscope so the value rises again to a final score of 10.7%.[243]

Similar to the aggregated results of the 32 buildings we can calculate the improvements:

- When we use the 17.9% value of the *zero* column as the maximum, then the improvement of *normal* over *zero* is about 40%. The improvement of *normal* over *onlyFirst* is just below 4%.
- When we use the 11.4% value from the *onlyFirst* column at the maximum, then the improvement of *normal* over *firstOnly* is at 6%

We can argue that the low positive impact of the various classification concepts on the Kaleidoscope might be due to the simple and clean shape of the cylinder. Though we have chosen the Kaleidoscope in the first place, because of these characteristics.[244]

243 It is a coincident that the *normal* value of the Kaleidoscope is at 10.7%, which is the same value like the average of all 32 buildings in Figure 319.

244 See chapter 6.3.

#	Picto	Building	normal		withSec		firstDefRef		firstDefaults		firstOnly		zero	
		Mean	10.7	7.2	14.0	11.8	11.6	9.8	12.3	11.1	13.7	15.7	21.3	24.5
1 A1			9.4	8.2	10.3	10.1	9.2	9.9	10.8	13.5	11.3	15.0	23.6	26.8
2 A2			8.9	12.8	30.3	37.4	13.9	14.6	15.5	16.4	13.5	15.8	20.5	21.9
3 A3			11.7	12.7	19.3	23.2	19.3	23.2	20.7	18.4	14.3	19.3	24.6	23.4
4 B1			9.0	10.4	12.9	16.6	14.1	16.1	17.2	24.2	16.9	22.9	23.3	28.5
5 B2			19.4	10.1	21.5	13.7	15.8	11.8	15.8	14.7	14.8	15.9	13.8	12.0
6 B3			9.0	9.3	12.3	6.1	12.3	6.1	16.0	17.3	15.6	13.0	22.7	24.0
7 C1			7.3	5.5	7.4	8.1	9.4	6.1	9.9	5.9	11.6	16.8	17.5	16.8
8 C2			14.0	6.3	12.3	8.6	24.1	5.1	22.7	5.1	29.9	32.9	28.8	33.2
9 C3			5.0	2.6	20.1	23.4	4.7	1.8	7.1	4.7	6.7	3.7	17.8	20.9
10 D1			11.6	7.7	12.7	9.9	7.4	6.1	12.4	12.5	15.8	17.9	18.1	25.9
11 D2			11.7	8.9	12.6	7.8	16.1	20.4	10.0	10.3	13.3	21.0	18.9	15.1
12 D3			9.3	5.4	16.2	16.1	20.6	11.9	11.8	8.4	20.0	20.6	20.2	20.6
13 E1			18.1	10.1	17.4	9.5	15.2	8.6	18.4	15.7	21.9	26.8	22.3	22.3
14 E2			18.1	15.8	18.4	18.8	6.8	4.4	19.7	17.7	22.1	29.2	25.4	23.1
15 E3			10.7	7.9	9.0	8.9	11.6	7.6	14.5	9.6	11.4	5.5	17.9	15.9
16 F1			8.9	9.3	10.0	13.2	10.0	13.2	8.6	14.0	8.0	13.6	25.1	27.3
17 F2			8.6	5.4	23.5	12.4	12.7	14.0	10.1	10.6	7.8	7.5	28.0	32.7
18 F3			9.2	12.1	7.1	8.1	7.0	8.0	4.8	5.3	5.0	6.0	23.5	22.4
19 G1			7.2	4.6	15.1	9.7	9.5	10.0	5.9	7.3	6.0	6.5	24.1	28.4
20 G2			8.4	4.8	8.6	3.1	8.6	3.1	9.2	3.3	8.3	3.6	11.2	11.1
21 G3			17.7	13.6	20.6	11.2	16.3	12.6	14.1	11.9	16.9	18.9	19.0	16.1
22 H1			13.6	5.9	18.7	15.3	7.8	4.5	8.1	6.1	11.2	9.6	24.6	28.1
23 H2			7.8	7.3	8.0	9.8	7.8	9.5	8.8	8.0	11.0	10.5	15.9	18.0
24 H3			6.1	3.8	29.5	25.0	7.8	7.2	8.5	6.1	11.8	8.7	20.9	22.8
25 S1			6.9	10.3	5.7	3.9	7.2	4.6	8.8	6.8	9.3	3.9	15.8	10.8
26 T1			6.7	4.6	10.6	3.4	10.8	3.4	12.0	8.5	12.6	11.9	23.0	34.8
27 U1			14.2	6.3	13.7	5.5	17.4	27.5	19.9	11.0	36.0	63.2	21.1	30.1
28 V1			7.2	0.1	8.5	3.2	7.2	1.9	8.6	0.1	7.7	2.3	19.6	19.4
29 W1			22.9	4.7	15.8	7.1	16.5	5.9	17.5	11.1	19.1	12.1	25.4	44.8
30 X1			9.0	1.8	8.2	3.1	12.2	14.0	14.3	17.5	13.8	19.1	20.2	32.6
31 Y1			5.5	0.2	6.7	5.0	6.7	3.9	6.9	9.4	8.2	11.3	21.6	29.3
32 Z1			11.3	1.0	10.5	19.6	10.5	19.6	11.1	17.5	11.1	17.5	24.0	41.4

Table 38: impression with faded values

As this is the first occurrence of the result table we will repeat a quick reference of the five columns alternative titles:

normal: Rules
withSec: Syntax Tree
firstDefRef: Weak References
firstDefaults: Periphrase implicit
firstOnly: Periphrase explicit

12.2.3. Result Tables

We will now to look at result tables that contain 32 pavilions. Before we dive into the numeric results, we will look at the tabular layout of the tables. Table 38 shows "an impression" of the main result table. The numeric values are explicitly faded out. This fade allows us to see the colour gradient better, which is obstructed in the following pages were we focus on the numeric results. The following pages repeat the table a four times. Though the repetition allows for a few variations.

- Table 39 uses a vertical row-centric visualisation.
- Table 40 uses again the column-centric visualisation.

- Table 41 uses the column-centric visualisation and points out problematic pavilions.
- Table 42 switches the gradient columns from “main” to “sibling only” sub-column.

In the print version of this thesis there are opposing spreads. The print page on the left of the spread is the table. The print page to the right of the spread has space to show additional photographs of the singled out pavilions.

We repeat the whole table four times and mark up specific rows. Often it is easier to see a spike or dip in the gradient colour when it is shown surrounded by more levelled values from other pavilions. The annotations sometimes reference more then one row.

Similar to the previous section, the numbers represent the delta between *empirical data* and *calculated data*. Therefore the smaller the number the better the match.

General table layout:

- The top row shows the mean values of the 32 data rows below. We have already discussed these in 12.2.1.
- The numbers in the green to red gradient cells represent the aggregated average of the curated group plus the additional buildings. These correspond to the Tables 22 up to 37. For instance for pavilion A1 this includes: A2, A3, A4, A5, A6, A7, B1, B2, B3, C1, C2, D1.
- The light grey number in the cells with the white background represent the result of “just the curated group”. For instance for pavilion A1 this includes: A2, A3, A4, A5, A6, A7. At a first glance we can observe that these results are generally better. But the curated groups only consist of seven or even just three pavilions therefore these numbers are not as meaningful as the bigger group.
- A gradient background *cell* to the left and a white background cell to the right make up a pair. Similar a gradient background *column* to the left and a white background column to the right make up a pair. Six of these paired columns exist.

The following list describe the first four *supporting columns* from left to right:

- A light grey number to identify the 32 rows.
- A short id like A1, A2, A3, B1, etc., which identifies the World Exposition pavilion. This short id can be used with the Tables 22 up to 37 for a quick reference. This short id also allows to seek the full details of a pavilion in Appendix A (19.1). The Appendix data includes additional photographs and the full classification.
- “Picto” is a pictogram of the classification data. It gives a first impression if a building requires a lot of Periphrase information, and includes a Syntax Tree. With the *fading away* of some Syntax Tree branches we also can see how significant the other

distinct building parts have been. The pictograms are explained in the introduction of chapter 12 and in the Figures 306 and 307.

- “Building” are tiny thumbnails that should give a visual hint which data is associated with which building. These are the same photographs as at the top of Tables 22 up to 37.

#	Picto	Building	normal	withSec	firstDefRef	firstDefaults	firstOnly	zero
		Mean	10.7% / 7.2%	14.0% / 11.8%	11.6% / 9.8%	12.3% / 11.1%	13.7% / 15.7%	21.3% / 24.5%
1 A1			9.4% / 8.2%	10.3% / 10.1%	9.2% / 9.9%	10.8% / 13.5%	11.3% / 15.0%	23.6% / 26.8%
2 A2			8.9% / 12.8%	30.3% / 37.4% (3b)	13.9% / 14.6%	15.5% / 16.4%	13.5% / 15.8%	20.5% / 21.9%
3 A3			11.7% / 12.7%	19.3% / 23.2%	19.3% / 23.2%	20.7% / 18.4%	14.3% / 19.3%	24.6% / 23.4%
4 B1			9.0% / 10.4% (1c)	12.9% / 16.6% (1b)	14.1% / 16.1% (1a)	17.2% / 24.2%	16.9% / 22.9%	23.3% / 28.5%
5 B2			19.4% / 10.1%	21.5% / 13.7%	15.8% / 11.8%	15.8% / 14.7%	14.8% / 15.9%	13.8% / 12.0%
6 B3			9.0% / 9.3%	12.3% / 6.1%	12.3% / 6.1%	16.0% / 17.3%	15.6% / 13.0%	22.7% / 24.0%
7 C1			7.3% / 5.5% (2c)	7.4% / 8.1%	9.4% / 6.1%	9.9% / 5.9%	11.6% / 16.8%	17.5% / 16.8%
8 C2			14.0% / 6.3% (2b)	12.3% / 8.6%	24.1% / 5.1%	22.7% / 5.1%	29.9% / 32.9%	28.8% / 33.2%
9 C3			5.0% / 2.6% (2a)	20.1% / 23.4% (2d)	4.7% / 1.8%	7.1% / 4.7%	6.7% / 3.7%	17.8% / 20.9%
10 D1			11.6% / 7.7%	12.7% / 9.9%	7.4% / 6.1%	12.4% / 12.5%	15.8% / 17.9%	18.1% / 25.9%
11 D2			11.7% / 8.9%	12.6% / 7.8%	16.1% / 20.4%	10.0% / 10.3%	13.3% / 21.0%	18.9% / 15.1%
12 D3			9.3% / 5.4%	16.2% / 16.1%	20.6% / 11.9%	11.8% / 8.4%	20.0% / 20.6%	20.2% / 20.6%
13 E1			18.1% / 10.1%	17.4% / 9.5%	15.2% / 8.6%	18.4% / 15.7%	21.9% / 26.8%	22.3% / 22.3%
14 E2			18.1% / 15.8%	18.4% / 18.8%	6.8% / 4.4%	19.7% / 17.7%	22.1% / 29.2%	25.4% / 23.1%
15 E3			10.7% / 7.9%	9.0% / 8.9%	11.6% / 7.6%	14.5% / 9.6%	11.4% / 5.5%	17.9% / 15.9%
16 F1			8.9% / 9.3%	10.0% / 13.2%	10.0% / 13.2%	8.6% / 14.0%	8.0% / 13.6%	25.1% / 27.3%
17 F2			8.6% / 5.4%	23.5% / 12.4% (3a)	12.7% / 14.0%	10.1% / 10.6%	7.8% / 7.5%	28.0% / 32.7%
18 F3			9.2% / 12.1%	7.1% / 8.1%	7.0% / 8.0%	4.8% / 5.3%	5.0% / 5.0%	23.5% / 22.4%
19 G1			7.2% / 4.6%	15.1% / 9.7% (3c)	9.5% / 10.0%	5.9% / 7.3%	6.0% / 6.5%	24.1% / 28.4%
20 G2			8.4% / 4.8%	8.6% / 3.1%	8.6% / 3.1%	9.2% / 3.3%	8.3% / 3.6%	11.2% / 11.1%
21 G3			17.7% / 13.6%	20.6% / 11.2%	16.3% / 12.6%	14.1% / 11.9%	16.9% / 18.9%	19.0% / 16.1%
22 H1			13.6% / 5.9%	18.7% / 15.3% (3d)	7.8% / 4.5%	8.1% / 6.1%	11.2% / 9.6%	24.6% / 28.1%
23 H2			7.8% / 7.3%	8.0% / 9.8%	7.8% / 9.5%	8.8% / 8.0%	11.0% / 10.5%	15.9% / 18.0%
24 H3			6.1% / 3.8% (4b)	29.5% / 25.0% (4a)	7.8% / 7.2%	8.5% / 6.1%	11.8% / 8.7%	20.9% / 22.8%
25 S1			6.9% / 10.3%	5.7% / 3.9%	7.2% / 4.6%	8.8% / 6.8%	9.3% / 3.9%	15.8% / 10.8%
26 T1			6.7% / 4.6%	10.6% / 3.4%	10.8% / 3.4%	12.0% / 8.5%	12.6% / 11.9%	23.0% / 34.8%
27 U1			14.2% / 6.3%	13.7% / 5.5%	17.4% / 27.5%	19.9% / 11.0%	36.0% / 63.2%	21.1% / 30.1%
28 V1			7.2% / 0.1%	8.5% / 3.2%	7.2% / 1.9%	8.6% / 0.1%	7.7% / 2.3%	19.6% / 19.4%
29 W1			22.9% / 4.7%	15.8% / 7.1%	16.5% / 5.9%	17.5% / 11.1%	19.1% / 12.1%	25.4% / 44.8%
30 X1			9.0% / 1.8%	8.2% / 3.1%	12.2% / 14.0%	14.3% / 17.5%	13.8% / 19.1%	20.2% / 32.6%
31 Y1			5.5% / 0.2%	6.7% / 5.0%	6.7% / 3.9%	6.9% / 9.4%	8.2% / 11.3%	21.6% / 29.3%
32 Z1			11.3% / 1.0%	10.5% / 19.6%	10.5% / 19.6%	11.1% / 17.5%	11.1% / 17.5%	24.0% / 41.4%

1


2


3


4


Table 39: Performance of conceptual features with aggregated values at the top and per pavilion values below.
Special markup for pavilions B1, C3, F2 and H3.
The stripes style of the background coloured cells should assist the eye to follow how the values change within a row.

We start with Table 39.

(1) B1 - Expo 1970 Soviet Union Pavilion (Osaka) (see also Figure 321) is modelled as a single distinct building part, and therefore consist only of one Periphrase. Still it gets consistent improvement with three new classification concepts (1a), (1b), (1c). Column *normal* (1c) is mainly about composition and Syntax Tree rules. The Soviet pavilion benefits from this indirectly. Buildings that are compared with the Soviet Pavilion might have compositions and Syntax Trees.

(2) C3 - Expo 1967 France Pavilion (Montreal) (see also Figure 322) is a positive surprise. It was actually added in a curated group together with the repeating boxy buildings of the "hidden simple" group (2a), (2b), (2c). It was added as a *distraction* so the groups theme is not to obvious for the participants in the empirical data gathering. It is one of

the most complex buildings in this research. The same effect that we describe next for (3) and (4) can also be observed in (2d).

(3) F2 - Expo 2010 Japan Pavilion (Shanghai) was modelled as a composition of two Periphrases. Though the second Periphrase if only of *minor* significance. The negative spike at the *withSec/Syntax Tree* column (3a) can be associated with the mixed bag of composition items triggered by the addition of the second distinct building part. The second building part is the block shaped annex in the back. It is a very different building shape compared to the main part. We can observe this negative impact in a few buildings like C3 (2b), F2 (3a), A2 (3b), G1 (3c), H1 (3d) and H3 (4a) We will experiment with dropping minor composition branches in chapter 12.4.2.

(4) H3 - Expo 2010 Australia Pavilion (Shanghai) (see also Figure 323 below, as well as Figures 308, 309 and 310) was modelled as a composition of two Periphrases. Again the second Periphrase if only of *minor* significance. The negative spike at the *withSec/ Syntax Tree* (4a) column can be attributed to the second distinct building part. The part is a tube like spiral ramp that goes right through the main distinct building part. The geometry of the spiral is very different and therefore attracts a lot of false positives. Once the composition rules are applied the spike is mitigated (4b).

Figure 321: B1 - Expo 1970 Soviet Union Pavilion (Osaka)

Additional aerial view of the back side.

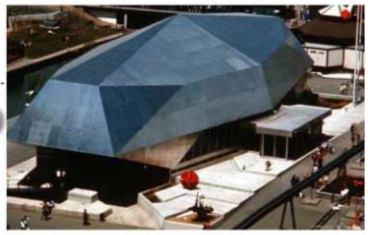
Figure 322: C3 - Expo 1967 France Pavilion (Montreal)

Additional view from pedestrian level.

Figure 323: H3 - Expo 2010 Australia Pavilion (Shanghai)

Additional detail view of, that shows the spiral.

#	Picto	Building	normal		withSec		firstDefRef		firstDefaults		firstOnly		zero	
		Mean	10.7%	7.2%	14.0%	11.8%	11.6%	9.8%	12.3%	11.1%	13.7%	15.7%	21.3%	24.5%
1 A1			9.4%	8.2%	10.3%	10.1%	9.2%	9.9%	10.8%	13.5%	11.3%	15.0%	23.6%	26.8%
2 A2			8.9%	12.8%	30.3%	37.4%	13.9%	14.6%	15.5%	16.4%	13.5%	15.8%	20.5%	21.9%
3 A3			11.7%	12.7%	19.3%	23.2%	19.3%	23.2%	20.7%	18.4%	14.3%	19.3%	24.6%	23.4%
4 B1			9.0%	[illegible]	12.9%	[illegible]	14.1%	16.1%	17.2%	24.2%	16.9%	22.9%	23.3%	28.5%
5 B2			19.4%	10.1%	21.5%	13.7%	15.8%	11.8%	15.8%	14.7%	14.8%	15.9%	13.8%	12.0%
6 B3			9.0%	9.3%	12.3%	6.1%	12.3%	6.1%	16.0%	17.3%	15.6%	13.0%	22.7%	24.0%
7 C1			7.3%	5.5%	7.4%	8.1%	9.4%	6.1%	9.9%	5.9%	11.6%	16.8%	17.5%	16.8%
8 C2			14.0%	6.3%	12.3%	8.6%	24.1%	5.1%	22.7%	5.1%	29.9%	32.9%	28.8%	33.2%
9 C3			5.0%	2.6%	20.1%	23.4%	4.7%	1.8%	7.1%	4.7%	6.7%	3.7%	17.8%	20.9%
10 D1			11.6%	7.7%	12.7%	9.9%	7.4%	6.1%	12.4%	12.5%	15.8%	17.9%	18.1%	25.9%
11 D2			11.7%	8.9%	12.6%	7.8%	16.1%	20.4%	10.0%	10.3%	13.3%	21.0%	18.9%	15.1%
12 D3			9.3%	5.4%	16.2%	16.1%	20.6%	11.9%	11.8%	8.4%	20.0%	20.6%	20.2%	20.6%
13 E1			18.1%	10.1%	17.4%	9.5%	15.2%	8.6%	18.4%	15.7%	21.9%	26.8%	22.3%	22.3%
14 E2			18.1%	15.8%	18.4%	18.8%	6.8%	4.4%	19.7%	17.7%	22.1%	29.2%	25.4%	23.1%
15 E3			10.7%	7.9%	9.0%	8.9%	11.6%	7.6%	14.5%	9.6%	11.4%	5.5%	17.9%	15.9%
16 F1			8.9%	9.3%	10.0%	13.2%	10.0%	13.2%	8.6%	14.0%	8.0%	13.6%	25.1%	27.3%
17 F2			8.6%	5.4%	23.5%	12.4%	12.7%	14.0%	10.1%	10.6%	7.8%	7.5%	28.0%	32.7%
18 F3			9.2%	12.1%	7.1%	8.1%	7.0%	8.0%	4.8%	5.3%	5.0%	5.0%	23.5%	22.4%
19 G1			7.2%	[illegible]	15.1%	9.7%	9.5%	10.0%	5.9%	7.3%	6.0%	[illegible]	24.1%	28.4%
20 G2			8.4%	4.8%	8.6%	3.1%	8.6%	3.1%	9.2%	3.3%	8.3%	3.6%	11.2%	11.1%
21 G3			17.7%	13.6%	20.6%	11.2%	16.3%	12.6%	14.1%	11.9%	16.9%	18.9%	19.0%	16.1%
22 H1			13.6%	5.9%	18.7%	15.3%	7.8%	4.5%	8.1%	6.1%	11.2%	9.6%	24.6%	28.1%
23 H2			7.8%	7.3%	8.0%	9.8%	7.8%	9.5%	8.8%	8.0%	11.0%	10.5%	15.9%	18.0%
24 H3			6.1%	3.8%	29.5%	25.0%	7.8%	7.2%	8.5%	6.1%	11.8%	8.7%	20.9%	22.8%
25 S1			6.9%	10.3%	5.7%	3.9%	7.2%	4.6%	8.8%	6.8%	9.3%	3.9%	15.8%	10.8%
26 T1			6.7%	4.6%	10.6%	3.4%	10.8%	3.4%	12.0%	8.5%	12.6%	11.9%	23.0%	34.8%
27 U1			14.2%	6.3%	13.7%	5.5%	17.4%	27.5%	19.9%	11.0%	36.0%	63.2%	21.1%	30.1%
28 V1			7.2%	[illegible]	8.5%	3.2%	7.2%	1.9%	8.6%	0.1%	7.7%	[illegible]	19.6%	19.4%
29 W1			22.9%	4.7%	15.8%	7.1%	16.5%	5.9%	17.5%	11.1%	19.1%	12.1%	25.4%	44.8%
30 X1			9.0%	1.8%	8.2%	3.1%	12.2%	14.0%	14.3%	17.5%	13.8%	19.1%	20.2%	32.6%
31 Y1			5.5%	0.2%	6.7%	5.0%	6.7%	3.9%	6.9%	9.4%	8.2%	11.3%	21.6%	29.3%
32 Z1			11.3%	1.0%	10.5%	19.6%	10.5%	19.6%	11.1%	17.5%	11.1%	17.5%	24.0%	41.4%

1

2


3

4


Table 40: Performance of conceptual features with aggregated values at the top and per pavilion values below. Special markup for pavilions A3, E3, F3 and U1.

We continue with Table 40.

(1) A3 - Expo 1967 Europe Pavilion (Montreal) (see also Figure 324) scores low up to column *withSec/Syntax Tree* (1a). It is modelled as a single Periphrase with no composition and therefore no Syntax Tree. Still it benefits significantly from the Syntax Tree rules (1b). This is due to two effects. On the one hand it peer buildings in the curated group A, like A2, A4, A7 which contain Syntax Trees, are described better with the rules. The part which is similar to the shape of the Europe Pavilion gets more emphasis. On the other hand, building where the Syntax Tree composition is important like D3 - Expo 1967 Pulp and Paper Corporate Pavilion (Montreal) get pushed further away. This is due to *rule of composition present* which applies to a comparison when there is a composition present in one building, but none in the other building.

(2) E3 - Expo 1967 Kaleidoscope Pavilion (Montreal) was already covered in chapter 12.2.2 in more detail. In (2) we can see it in context to other data rows.

(3) F3 - Expo 2000 Japan Pavilion (Hannover) (see also Figure 325) has an already good value of 5.0% in the *firstOnly / Periphrase explicit* column (3a). The final score of 9.2% is less good (3b). The *firstOnly* column contains two contributions from a single classification set that are marked significant: curvatureUndulation as well as curvatureConcaveConvex. Additionally edgeViewSmooth and edgePlaneSmooth amplify the classification. These relative seldom classification items seem to describe the building shape identity well. Additional classification concepts pull in less matching buildings. Still the final score of 9.2% (3b) is better then the overall average of 10.7%.[245]

(4) U1 - Expo 1967 Netherlands Pavilion (Montreal) (see also Figure 326) has an opposite story of the Japan Pavilion in (3). The explicit significant textureFacetedRegular and the Proportion data of a single block can not describe the building shape. It scores a bad 36.0% (4a) in the *firstOnly / Periphrase explicit* column. The classification relies on the default values which describe the perfect cube.The composition of different blocks with spacingPlanarOverlapPartial as well the self-similarity classification items from size-SmallerSlightly, varietyMinor and randomnessMinor are an import part of the building shape identity. The building arrive at a more acceptable 14.2% in the *normal / Rules* column (4b).

Figure 324: A3 - Expo 1967 Europe Pavilion (Montreal)

Additional view from pedestrian level

Figure 325: F3 - Expo 2000 Japan Pavilion (Hannover)

Additional aerial view

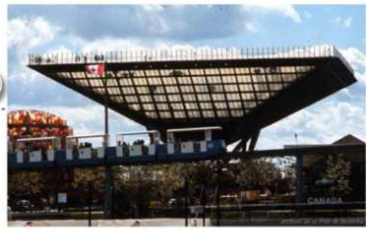
Figure 326: U1 - Expo 1967 Netherlands Pavilion (Montreal)

Additional view from pedestrian level

245 We can speculate that the concepts would do less harm when we would have 800 instead of 80 World Exposition pavilions.

#	Picto	Building	normal		withSec		firstDefRef		firstDefaults		firstOnly		zero	
		Mean	10.7%	7.2	14.0%	11.8	11.6%	9.8	12.3%	11.1	13.7%	15.7	21.3%	24.5
1 A1			9.4%	8.2	10.3%	10.1	9.2%	9.9	10.8%	13.5	11.3%	15.0	23.6%	26.8
2 A2			8.9%	12.8	30.3%	37.4	13.9%	14.6	15.5%	16.4	13.5%	15.8	20.5%	21.9
3 A3			11.7%	12.7	19.3%	23.2	19.3%	23.2	20.7%	18.4	14.3%	19.3	24.6%	23.4
4 B1			9.0%	10.4	12.9%	16.6	14.1%	16.1	17.2%	24.2	16.9%	22.9	23.3%	28.5
5 B2			19.4% (1c)	10.1	21.5% (1b)	13.7	15.8% (1a)	11.8	15.8%	14.7	14.8%	15.9	13.8%	12.0
6 B3			9.0%	9.3	12.3%	6.1	12.3%	6.1	16.0%	17.3	15.6%	13.0	22.7%	24.0
7 C1			7.3%	5.5	7.4%	8.1	9.4%	6.1	9.9%	5.9	11.6%	16.8	17.5%	16.8
8 C2			14.0%	6.3	12.3%	8.6	24.1%	5.1	22.7%	5.1	29.9%	32.9	28.8%	33.2
9 C3			5.0%	2.6	20.1%	23.4	4.7%	1.8	7.1%	4.7	6.7%	3.7	17.8%	20.9
10 D1			11.6%	7.7	12.7%	9.9	7.4%	6.1	12.4%	12.5	15.8%	17.9	18.1%	25.9
11 D2			11.7%	8.9	12.6%	7.8	16.1%	20.4	10.0%	10.3	13.3%	21.0	18.9%	15.1
12 D3			9.3%	5.4	16.2%	16.1	20.6%	11.9	11.8%	8.4	20.0%	20.6	20.2%	20.6
13 E1			18.1%	10.1	17.4%	9.5	15.2%	8.6	18.4%	15.7	21.9%	26.8	22.3%	22.3
14 E2			18.1% (3b)	15.8	18.4%	18.8	6.8% (3a)	4.4	19.7%	17.7	22.1%	29.2	25.4%	23.1
15 E3			10.7%	7.9	9.0%	8.9	11.6%	7.6	14.5%	9.6	11.4%	5.5	17.9%	15.9
16 F1			8.9%	9.3	10.0%	13.2	10.0%	13.2	8.6%	14.0	8.0%	13.6	25.1%	27.3
17 F2			8.6%	5.4	23.5%	12.4	12.7%	14.0	10.1%	10.6	7.8%	7.5	28.0%	32.7
18 F3			9.2%	12.1	7.1%	8.1	7.0%	8.0	4.8%	5.3	5.0%	5.0	23.5%	22.4
19 G1			7.2% (4c)	4.6	15.1%	9.7	9.5%	10.0	5.9%	7.3	6.0%	6.5	24.1%	28.4
20 G2			8.4%	4.8	8.6%	3.1	8.6%	3.1	9.2%	3.3	8.3%	3.6	11.2%	11.1
21 G3			17.7% (4b)	13.6	20.6%	11.2	16.3%	12.6	14.1% (4a)	11.9	16.9%	18.9	19.0%	16.1
22 H1			13.6%	5.9	18.7%	15.3	7.8%	4.5	8.1%	6.1	11.2%	9.6	24.6%	28.1
23 H2			7.8%	7.3	8.0%	9.8	7.8%	9.5	8.8%	8.0	11.0%	10.5	15.9%	18.0
24 H3			6.1%	3.8	29.5%	25.0	7.8%	7.2	8.5%	6.1	11.8%	8.7	20.9%	22.8
25 S1			6.9%	10.3	5.7%	3.9	7.2%	4.6	8.8%	6.8	9.3%	3.9	15.8%	10.8
26 T1			6.7%	4.6	10.6%	3.4	10.8%	3.4	12.0%	8.5	12.6%	11.9	23.0%	34.8
27 U1			14.2%	6.3	13.7%	5.5	17.4%	27.5	19.9%	11.0	36.0%	63.2	21.1%	30.1
28 V1			7.2%	0.1	8.5%	3.2	7.2%	1.9	8.6%	0.1	7.7%	2.3	19.6%	19.4
29 W1			22.9% (5a)	[illegible]	15.8%	7.1	16.5%	5.9	17.5%	11.1	19.1%	12.1	25.4%	44.8
30 X1			9.0%	1.8	8.2%	3.1	12.2%	14.0	14.3%	17.5	13.8%	19.1	20.2%	32.6
31 Y1			5.5%	0.2	6.7%	5.0	6.7%	3.9	6.9%	9.4	8.2%	11.3	21.6%	29.3
32 Z1			11.3%	1.0	10.5%	19.6	10.5%	19.6	11.1%	17.5	11.1%	17.5	24.0%	41.4

1


2


3


4


Table 41: Performance of conceptual features with aggregated values at the top and per pavilion values below.
Special markup for pavilions B2, E1, E2 and G3.
These pavilions are challenging for the proposed classification system.

We continue with Table 41, which exposes some weaknesses in the proposed system.

(1) B2 - Expo 1967 United Kingdom Pavilion (Montreal) (see also Figure 327) has a tower part and a front building part. Both are substantial parts of the pavilion. The two parts have only textureStripedRegular in common. All other slots are different. The tower was chosen to be the main building shape. It does not perform well by itself with 15.8% in the *firstDefRef / Weak References* column (1a). Once the composition and the second Periphrase is added in *withSec / Syntax Tree* column (1b) the value degrades further. The building ends up with a less good 19.4% in (1c). A possible solution would be to decide that the United Kingdom contribution to Expo 1967 was actually two separate buildings: The tower and the front building. But when we look at photographs which contain surrounding pavilions we can see that there is some unity in the the building shape of the tower and the front building. It is also supported by the common white colour.

(2) E1 - Expo 1967 Canada Host-Pavilion (Montreal) (see also Figure 328) and
(3) E2 - Expo 2010 China Host Pavilion (Shanghai) are obviously related. This is backed by empirical data when we discuss curated group E. We can observe that the China Host Pavilion is benefiting from *firstDefRef / Weak References* (3a) with a value of 6.8%. Weak References help for instance in the *Tilt* classification set. There is a connection from tiltWidenSignificant with the tiltWidenComplete from the Canada Host Pavilion. This effect is repeated by other pavilions form the curated group. But the China Host Pavilion suffers from its composition. The composition is relative complex. The four legs are considered as one branch and the huge base as a further one (see Figures 267 up to 272, Figure 273 contains the Syntax Tree)[246]. The pavilion degrades from 6.8% to 18.1% in the *normal / Rules* column (3b). With the problems of B1 and E2, we could speculate that the composition concept introduced in this thesis can only handle simple arrangement. Though there are counter examples like C1, C2, D1, D2, D3, U1 and X1 that work well with composition.

(4) G3 - Expo 2000 Germany Host Pavilion (Hannover) (see also Figure 329) suffers from a related problem like the United Kingdom Pavilion (1). The roof and the base are modelled as two distinct building parts. Though it is one enclosed space. The two parts share very few common classification items. Just looking at the roof in *firstDefRef / Weak References* with 14.1% (4a) is better then considering the whole building with 17.7% (4b). G1 - Expo 1967 Soviet Union Pavilion (Montreal) (see Figure 347) has a similar setup, where the roof is the identity defining feature, (4c) though the composition does not have a similar negative impact.

(5) W1 - Expo 2010 Expo Culture Center Host Pavilion (Shanghai) (see Figures 333, 334 and 335 a few pages below) gets a significant hit once rules are added in the *normal / Rules* column (5a). There is unfortunately no obvious explanation for this effect.

Figure 327: B2 - Expo 1967 United Kingdom Pavilion (Montreal)

Additional aerial view of back side

Figure 328: E1 - Expo 1967 Canada Host-Pavilion (Montreal)

Additional aerial view

Figure 329: G3 - Expo 2000 Germany Host Pav. (Hannover)

Additional aerial view

246 We used the base of the China Host pavilion in the discussion of distinct building parts in chapter 6.1.

#	Picto	Building	normal		withSec		firstDefRef		firstDefaults		firstOnly		zero	
		Mean	10.7%	7.2%	14.0%	11.8%	11.6%	9.8%	12.3%	11.1%	13.7%	15.7%	21.3%	24.5%
1 A1			9.4%	8.2%	10.3%	10.1%	9.2%	9.9%	10.8%	13.5%	11.3%	15.0%	23.6%	26.8%
2 A2			8.9%	12.8%	30.3%	37.4%	13.9%	14.6%	15.5%	16.4%	13.5%	15.8%	20.5%	21.9%
3 A3			11.7%	12.7%	19.3%	23.2%	19.3%	23.2%	20.7%	18.4%	14.3%	19.3%	24.6%	23.4%
4 B1			9.0%	10.4%	12.9%	16.6%	14.1%	16.1%	17.2%	24.2%	16.9%	22.9%	23.3%	28.5%
5 B2			19.4%	10.1%	21.5%	13.7%	15.8%	11.8%	15.8%	14.7%	14.8%	15.9%	13.8%	12.0%
6 B3			9.0%	9.3%	12.3%	6.1%	12.3%	6.1%	16.0%	17.3%	15.6%	13.0%	22.7%	24.0%
C1			7.3%	5.5%	7.4%	8.1%	9.4%	6.1%	9.9%	5.9%	11.6%	16.8%	17.5%	16.8%
C2			14.0%	6.3% (2e)	12.3%	8.6% (2d)	24.1%	5.1% (2c)	22.7%	5.1% (2b)	29.9%	32.9% (2a)	28.8%	33.2%
9 C3			5.0%	2.6%	[illegible]	23.4%	[illegible]	1.8%	[illegible]	4.7%	[illegible]	3.7%	[illegible]	20.9%
10 D1			11.6%	7.7%	12.7%	9.9%	7.4%	6.1%	12.4%	12.5%	15.8%	17.9%	18.1%	25.9%
11 D2			11.7%	8.9%	12.6%	7.8%	16.1%	20.4%	10.0%	10.3%	13.3%	21.0%	18.9%	15.1%
12 D3			9.3%	5.4%	16.2%	16.1%	20.6%	11.9%	11.8%	8.4%	20.0%	20.6%	20.2%	20.6%
13 E1			18.1%	10.1%	17.4%	9.5%	15.2%	8.6%	18.4%	15.7%	21.9%	26.8%	22.3%	22.3%
14 E2			18.1%	15.8%	18.4%	18.8%	6.8%	4.4%	19.7%	17.7%	22.1%	29.2%	25.4%	23.1%
15 E3			10.7%	7.9%	9.0%	8.9%	11.6%	7.6%	14.5%	9.6%	11.4%	5.5%	17.9%	15.9%
16 F1			8.9%	9.3%	10.0%	13.2%	10.0%	13.2%	8.6%	14.0%	8.0%	13.6%	25.1%	27.3%
17 F2			8.6%	5.4%	23.5%	12.4%	12.7%	14.0%	10.1%	10.6%	7.8%	7.5%	28.0%	32.7%
18 F3			9.2%	12.1%	7.1%	8.1%	7.0%	8.0%	4.8%	5.3%	5.0%	5.0%	23.5%	22.4%
19 G1			7.2%	4.6%	15.1%	9.7%	9.5%	10.0%	5.9%	7.3%	6.0%	6.5%	24.1%	28.4%
20 G2			8.4%	4.8% (3b)	8.6%	3.1%	8.6%	3.1%	9.2%	3.3%	8.3%	3.6% (3a)	11.2%	11.1%
21 G3			17.7%	13.6%	20.6%	11.2%	16.3%	12.6%	14.1%	11.9%	16.9%	18.9%	[illegible]	16.1%
22 H1			13.6%	5.9%	18.7%	15.3%	7.8%	4.5%	8.1%	6.1%	11.2%	9.6%	24.6%	28.1%
23 H2			7.8%	7.3%	8.0%	9.8%	7.8%	9.5%	8.8%	8.0%	11.0%	10.5%	15.9%	18.0%
24 H3			6.1%	3.8%	29.5%	25.0%	7.8%	7.2%	8.5%	6.1%	11.8%	8.7%	20.9%	22.8%
25 S1			6.9%	10.3%	5.7%	3.9%	7.2%	4.6%	8.8%	6.8%	9.3%	3.9%	15.8%	10.8%
26 T1			6.7%	4.6%	10.6%	3.4%	10.8%	3.4%	12.0%	8.5%	12.6%	11.9%	23.0%	34.8%
27 U1			14.2%	6.3%	13.7%	5.5%	17.4%	27.5%	19.9%	11.0%	36.0%	63.2%	21.1%	30.1%
28 V1			7.2%	0.1%	8.5%	3.2%	7.2%	1.9%	8.6%	0.1%	7.7%	2.3%	19.6%	19.4%
29 W1			22.9%	4.7%	15.8%	7.1%	16.5%	5.9%	17.5%	11.1%	19.1%	12.1%	25.4%	44.8%
30 X1			9.0%	1.8%	8.2%	3.1%	12.2%	14.0%	14.3%	17.5%	13.8%	19.1%	20.2%	32.6%
31 Y1			5.5%	0.2%	6.7%	5.0%	6.7%	3.9%	6.9%	9.4%	8.2%	11.3%	21.6%	29.3%
32 Z1			11.3%	1.0%	10.5%	19.6%	10.5%	19.6%	11.1%	17.5%	11.1%	17.5%	24.0%	41.4%

1

2

3

4

Table 42: Performance of conceptual features with aggregated values at the top and per pavilion values below.
Special markup for pavilions C1, C2, G2.
This table switches the coloured-cells from the main data to the reduced siblings data

Table 42 switches the gradient colour columns from the main data to the data of the sibling buildings of the curated group.

(1) C1 - Expo 2010 Angola Pavilion (Shanghai) (see also Figure 330) and
(2) C2 - Expo 2010 Algeria Pavilion (Shanghai) (see also Figure 331) are from the curated group "Hidden Simple". There is a detailed discussion in chapter 10.5. We will look at the numbers from C2, though C1 has the same pattern. The main distinct building part of both is the hall. The classification of the hall relies heavily on *default values* that add all missing slots that lead towards the perfect cube. Therefore we can see a significant positive impact from 32.9% (2a) in *firstOnly / Periphrase explicit* to 5.1% (2b) in *firstDefaults / Periphrase implicit*. Adding Weak References hardly changes the value 5.1% (2c) in the *firstDefRef* column. Secondary Periphrases in (2d) and rules do not have a significant impact. The final value in the *normal / Rules* column arrives at 6.3% (2e). In chapter 10.5 we discuss how important the composition is for the identity of these pavilions. The fact

that both pavilions score better in the *firstDefaults / Periphrase implicit* (2b) column then in the *normal / Rules* column (2e) is partly misleading. They do so due to the curation of the 80 pavilions. These are the only block shaped halls. When we would have for instance 800 pavilions and dozens or hundred that are just boxes then the composition with the *identity tower* and the *porch* would be more valuable.

(3) G2 - Expo 2012 Hyundai Corporate Pavilion (Yeosu) (see also Figure 332) is an example of “A little bit of classification goes a long way”. It scores an already very good 3.6% in the *firstOnly / Periphrase explicit* column (3a). Its single Periphrase is packed with: three items from the Lattice classification set, two from the Feature classification set, and a significant Curvature and Angle View item. Only two slots are empty. Even with its final score of 4.8% (and 8.4% in the main data set) it is a positive example how the proposed classification concept can handle complex shapes.

(4) The values in the lower quarter with S1, T1, U1, V1, W1, X1, Y1, Z1 are not representative, as there are only three building in a curated group. The results like 0.4% are good, but not founded on enough data.

Figure 330: C1 - Expo 2010 Angola Pavilion (Shanghai)

Additional view

Figure 331: C2 - Expo 2010 Algeria Pavilion (Shanghai)

Additional view

Figure 332: G2 - Expo 2012 Hyundai Corporate Pav. (Yeosu)

Additional aerial view

Figure 333: W1 - Expo 2010 Expo Culture Center Host Pavilion (Shanghai)

Figure 334: W1 - Expo 2010 Expo Culture Center Host Pavilion (Shanghai)

Additional aerial view

Figure 335: W1 - Expo 2010 Expo Culture Center Host Pavilion (Shanghai)

Additional satellite view

12.3. Results of Classification Sets

We just saw, that the software implementation allows to turn on and off various *conceptual features*. Such feature toggles also exist for the *classification sets* of the Periphrase and the Syntax Tree. We will first look how different classification sets contribute in the Periphrase and later repeat it for the classification sets in the Syntax Tree.

The classifications sets are discussed in chapter 7.3 for the Periphrase and 8.2 for the Syntax Tree. For convenience we will give a visual overview of the ten Periphrase classification sets in Figure 336 and the six Syntax Tree classification sets in Figure 338.

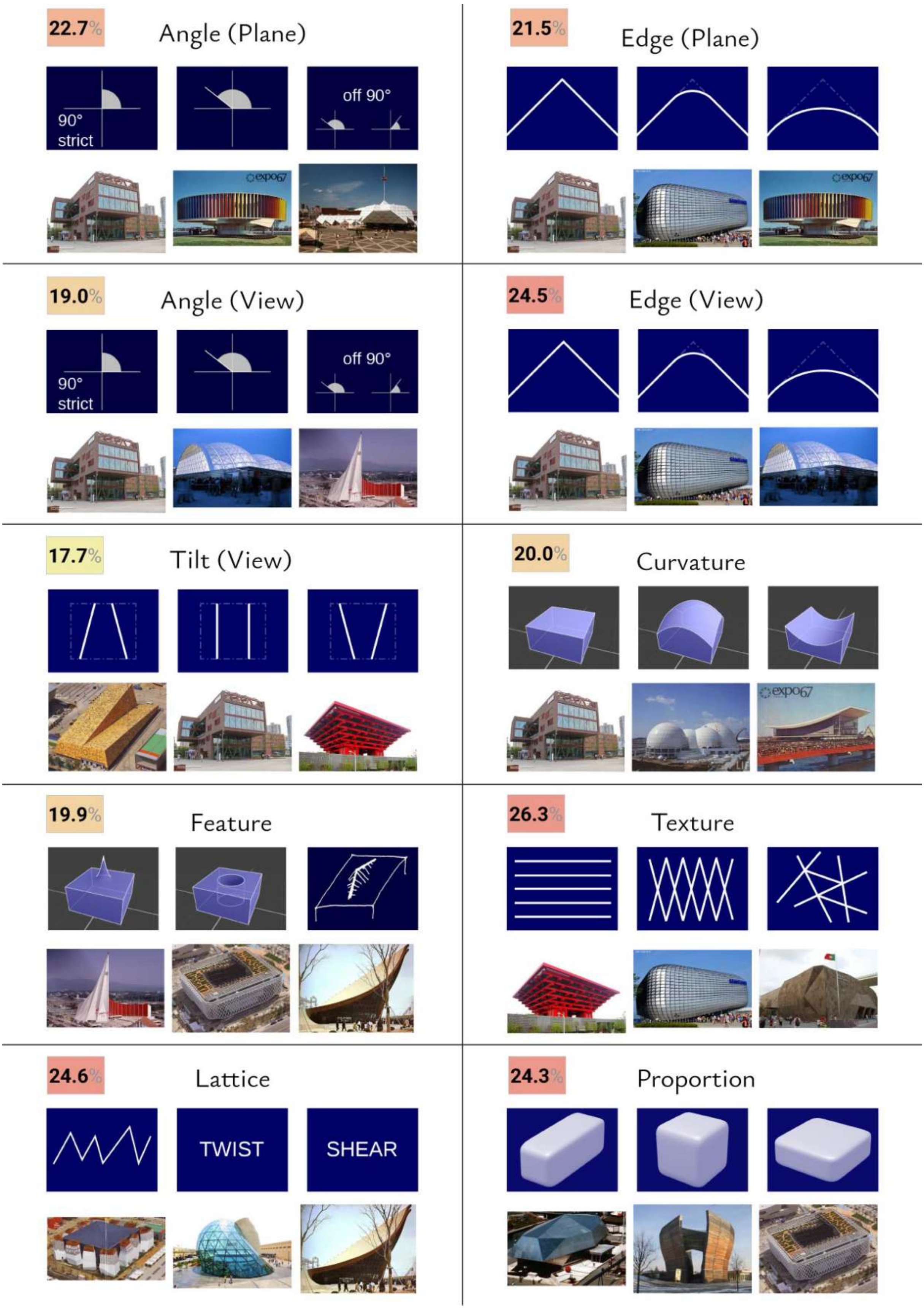


Figure 336: Overview of the ten classification sets used in a Periphrase. Each classification set lists three typical items and below each item is a World Exposition pavilion that shows an applied example. The classification sets are introduced in 6.5.2 and are discussed in more details in 7.3

12.3.1. Results of Periphrase Classification Sets

Table 43 shows the performance of the ten classification sets of the Periphrase. Figure 337 is a different visualisation of the "Integrated" column as a bar chart. Similar to the previous chapters: the lower the value the better. The numbers come as pairs. There is always the main number with a coloured background and an associated grey number to the right. The grey number describes the same setup but reduced to siblings in the curated groups[247]. The siblings usually perform better, but the mixed groups are more significance as they contain more backing data. The columns are as follows:

- Normal – Everything is turned on. The classification set in focus as well as all the other classification set are turned on. The value of 10.7% is the same in all columns.
- Turned Off – The classification set in focus is turned off, while all the other classification sets are still turned on. We can see the impact when it is missing.
- Integrated - The classification set in focus is turned on, while all the other classification sets are turned off. All conceptual features are turned on.
- Only One – The classification set in focus is turned on, while all the other classification sets are turned off. The Rules of chapter 9.7.3 are turned off. As a consequence of the absence of the rules, the values from the slots are not altered. Conceptual features like Weak References, Periphrase-Behaviour-Override, and the collection of all Periphrases in the Syntax tree are still active.
- Zero – The reference value that we discussed in the introduction of chapter 12.

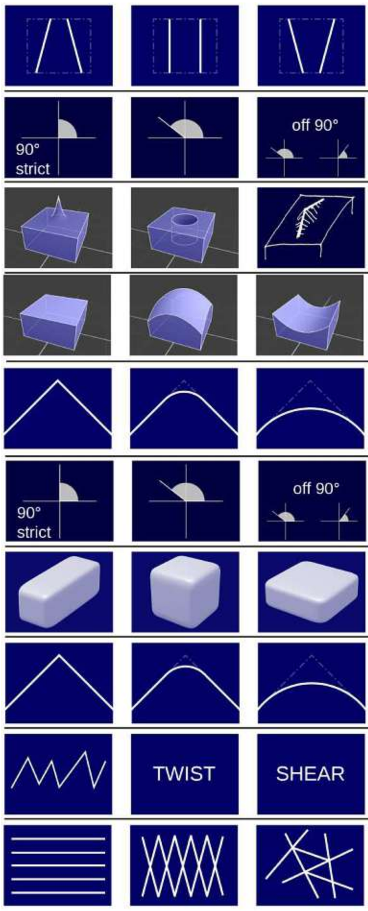
The results are ranked and discussed here based on the "Integrated" column in Table 43.

The *Tilt* classification set is the best performing one with a value of 17.7%. It is the top value in the dashed outlined column. It is a novel classification set developed in this thesis (see 7.3.3). It benefits from inputs from Vision as well as the the applied architecture space where gravity is a natural constraint. It is a positive and unanticipated result that the novel Tilt classification set is also the best performing one.

The *Angle-View* classification set is related to Tilt. It might indirectly benefit from the same forces that let Tilt perform well.

Feature and *Curvature* are at the third and forth position. There is a certain disjoint nature between these two sets. Many pavilions that benefit from *Feature* do less rely on *Curvature* and the other way around. We will discuss this observation it in 12.4.1 when we explore how well the two classification sets complement each other.

247 Curated groups are discussed in chapter 12.1.



	Normal		Turned off		Integrated		Only one		Zero	
Tilt	**10.7%**	7.2%	**11.9%**	8.5%	**17.7%**	15.6%	**18.3%**	17.1%	**21.3%**	24.5%
Angle-View	**10.7%**	7.2%	**11.5%**	8.1%	**19.0%**	16.4%	**19.9%**	18.4%	**21.3%**	24.5%
Feature	**10.7%**	7.2%	**11.6%**	8.5%	**19.9%**	19.9%	**20.5%**	19.4%	**21.3%**	24.5%
Curvature	**10.7%**	7.2%	**11.6%**	8.1%	**20.0%**	19.2%	**20.3%**	19.2%	**21.3%**	24.5%
Edge-Plane	**10.7%**	7.2%	**10.9%**	7.4%	**21.5%**	17.5%	**22.5%**	19.2%	**21.3%**	24.5%
Angle-Plane	**10.7%**	7.2%	**11.1%**	8.3%	**22.7%**	20.2%	**22.7%**	20.6%	**21.3%**	24.5%
Proportion	**10.7%**	7.2%	**11.2%**	7.9%	**24.4%**	23.0%	**25.1%**	24.4%	**21.3%**	24.5%
Edge-View	**10.7%**	7.2%	**11.2%**	7.6%	**24.5%**	21.6%	**22.4%**	21.4%	**21.3%**	24.5%
Lattice	**10.7%**	7.2%	**11.3%**	7.3%	**24.6%**	24.4%	**24.7%**	24.7%	**21.3%**	24.5%
Texture	**10.7%**	7.2%	**11.0%**	7.9%	**26.3%**	29.5%	**27.3%**	31.8%	**21.3%**	24.5%

Table 43: Performance of the classification sets of the Periphrase.

Edges in the *Plane* are often extruded and are then visible as walls from a pedestrian point of view. They are for example essential for the definition of "something similar to a cylinder" in the Kaleidoscope. Edge-Plane is the last classification set with a value of 21.5% that is approximate below/at the *Zero* reference column value of 21.3%.

The following five classification sets perform less well. It does not mean that they are of little value. They exist often as a complimentary or symmetrical construct or fill gaps that are hard to describe with the five better performing classification sets.

Angle-Plane is related to *Edge-Plane*. Similar angles are often visible in the joints of extruded walls. While Edge-Plane concentrates at a perception *quality* the Angle-View tries to cover the perceptual *quality* as well as the perceptual *quantity* of angles that are rooted in geometry. This seems to work out well for the second placed Angle-*View* but less for well for Angle-*Plane*. This might be connected to experiences like: it is hard to recognize the difference between angles from a pedestrian point of view. While the discussed effects of gravity and culture helps in Angle-View similar to Tilt, there is less help for Angle-Plane. It is hard to judge if an angle of a bigger building is exactly 90 degrees or if it is off. This is challenging from a real world pedestrian point of view as well as camera distorted photographs.

The *Proportions* classification set does not perform well. In Vision it is considered a quantitative feature. Many Vision studies point out the weak performance of *quantitative* features over *qualitative* features. But Vision is mainly concerned with human shape recognition within the first moments e.g. 100ms. The visual contact to buildings last usually longer.[248] Proportions have a special place in the architecture curriculum. They are considered essential to achieve certain positive aesthetics. While proportions have been carefully assigned to each pavilion their poor performance is still surprising.

The *Edge-View* classification set performs less well. This is surprising, because it should benefit from the same driving forces that benefit *Tilt* and *Curvature*. There is also some parallels to certain items in the *Feature* classification sets, like ridges and high points. One possible explanation is that it was neglected due to its overlap with these three more expressive sets.

The *Lattice* and *Texture* classification sets are at the end of the ranking. Though this is less surprising. They are not applied on many pavilions. Within the collection of 80 pavilions these sets serve to fill gaps that are hard to describe with the five better performing sets. The Lattice classification set can handle abstract transformations. This allows other classification sets to be cleaner and leave this concern to Lattice.

An argument that is valid for *Lattice* and *Texture* could be generalized. The collection of 80 World Exposition pavilions is limited. Often certain classification items are only used once or twice. Though the conceptual feature of *Weak References* is modelled to reduce this short coming. A collection with e.g. 800 pavilions would better show the impact and potential of the classification sets. Unfortunately this is out of scope for this thesis due to the associated work load.

248 In the empirical setup the participants had of course more time then a few hundred milliseconds to make up their mind. The participants also had multiple photographs of each pavilion to explore.

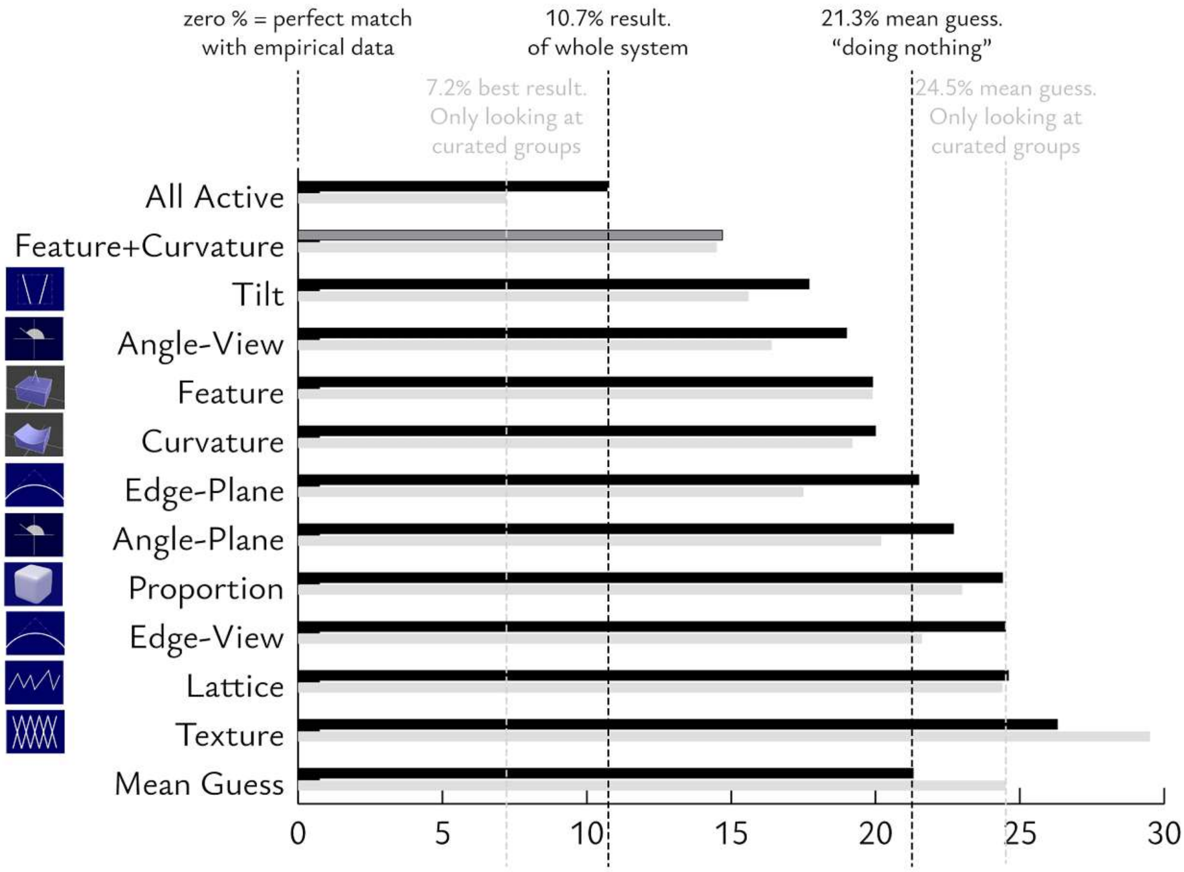


Figure 337: Performance of the classification sets of the Periphrase. Visualised as a bar chart.

12.3.2. Results of Syntax Tree Classification Sets

We can see an overview of the six Syntax Tree classification sets in Figure 338 . Table 44 is an unsorted view of the result for the comparison of empirical data and calculated data. Only 53 of 80 pavilions have a Syntax Tree. To make the result more meaningful only these 53 pavilions are included in the calculations.[249]

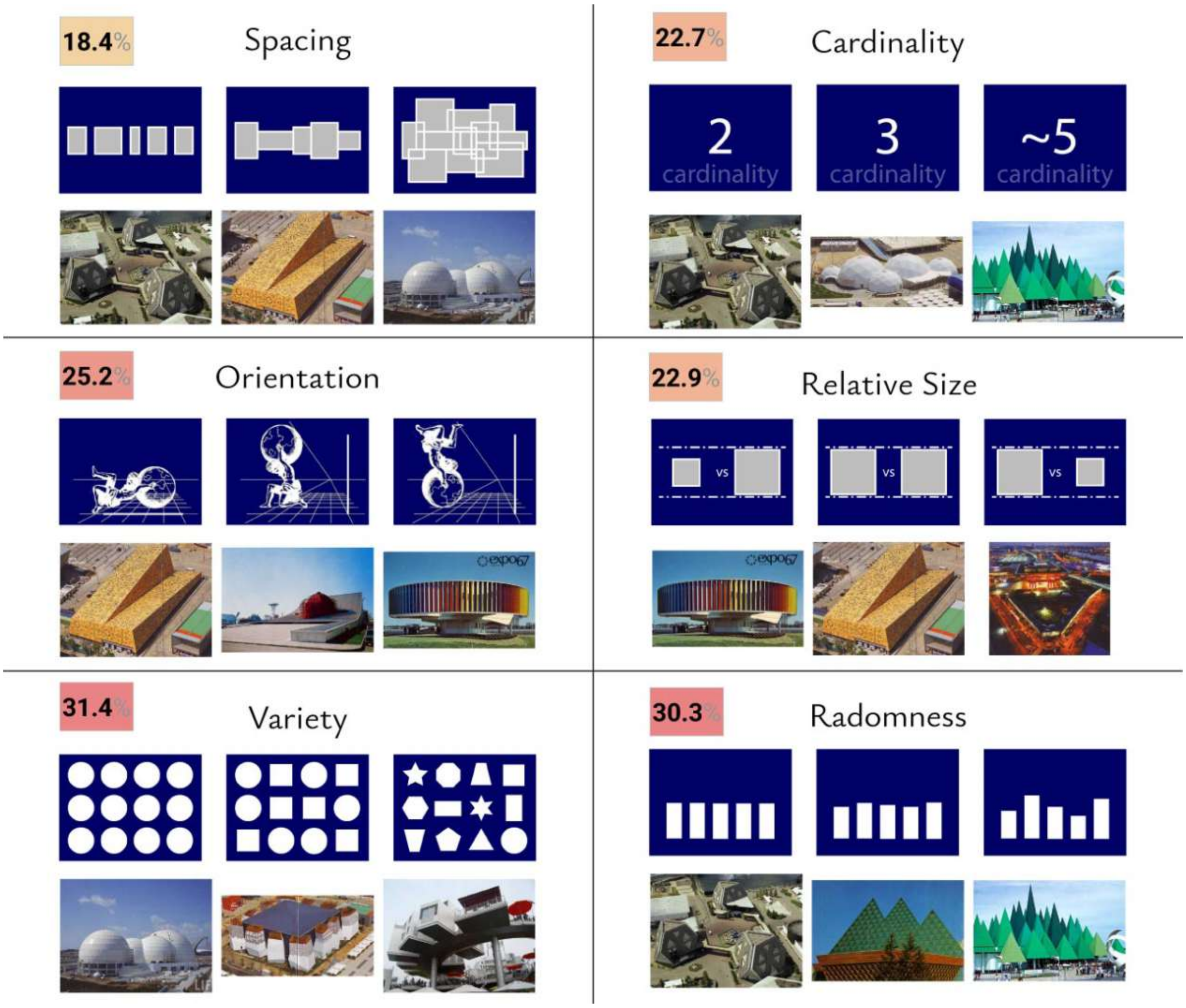


Figure 338: Overview of the six classification sets used in a Syntax Tree. Each classification set sows three typical items and below each item is a World Exposition pavilion that shows an applied example. The classification sets are introduced in 6.6.3 and are dicussed in more details in 8.2

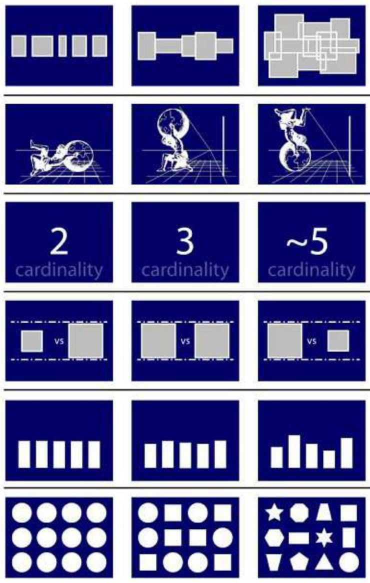
The *Spacing* classification set is present in all 53 Syntax Trees and does perform best with 18.4%. It is also the only classification set that is lower then the reference *Zero* value of 20.5%. From a Vision point of view it can be seen as a qualitative property.

Orientation and *Cardinality* are also present in all 53 Syntax Trees, always as dominated sub-branches below *Spacing*. In early stages of the research there was a single "arrangement" classification set. It got split up into Spacing, Orientation and Cardinality. Therefore it is less surprising that the relative abstract *Orientation* classification set can

249 Therefore the Normal and Zero values in Table 43 differs from the results of the Periphrase in Table 44. All 80 pavilions have at least one Periphrase.

not stand by itself. The more quantitative *Cardinality* classification set is performing better but is can also be considered to be part of the “arrangement” group.

The *Relative Size* classification set is present in all 53 Syntax Trees. It is a mixture of quantitative and qualitative concerns.



	Normal		Turned off		Integrated		Only one		Zero	
Spacing	12.3%	7.3%	12.2%	7.0%	18.4%	22.6%	40.0%	21.1%	20.5%	22.9%
Orientation	12.3%	7.3%	12.6%	7.2%	25.2%	22.8%	40.0%	21.1%	20.5%	22.9%
Cardinality	12.3%	7.3%	12.4%	7.2%	22.7%	26.7%	40.0%	21.1%	20.5%	22.9%
Relative Size	12.3%	7.3%	12.4%	7.2%	22.9%	20.5%	40.0%	21.1%	20.5%	22.9%
Radomness	12.3%	7.3%	12.4%	7.4%	31.4%	21.1%	40.0%	21.1%	20.5%	22.9%
Variety	12.3%	7.3%	12.4%	7.3%	30.3%	19.9%	40.0%	21.1%	20.5%	22.9%

Table 44: Performance of the classification sets of the Syntax Tree.

Size Randomness and *Variety* are only applied when at least three distinct building parts are described in a single branch. They are also used to model self-similarity. Only 22 of the pavilions use these classification sets[250]; 31 are not using them. Therefore it is no surprise that they do not function on their own.

250 The following pavilions contain Size Randomness and Variety:
D1 - Expo 1967 Ontario Region Pavilion (Montreal)
D2 - Expo 1967 Africa Group Pavilion (Montreal)
D3 - Expo 1967 Pulp and Paper Corporate Pavilion (Montreal)
D4 - Expo 2010 Wanke Corporate Pavilion (Shanghai)
D5 - Expo 2010 Cases Theme Pavilion (Shanghai)
D6 - Expo 2010 Netherlands Pavilion (Shanghai)
D7 - Expo 1970 Bulgaria Pavilion (Osaka)
E2 - Expo 2010 China Host Pavilion (Shanghai)
E7 - Expo 2010 South Korea Pavilion (Shanghai)
F6 - Expo 2012 Ocean Coast Pavilion (Yeosu)
G5 - Expo 1967 Italy Pavilion (Montreal)
H1 - Expo 2010 Chile Pavilion (Shanghai)
H4 - Expo 2010 Private Enterprise Corporate Pavilion (Shanghai)
S3 - Expo 1967 Czechoslovakia Pavilion (Montreal)
U1 - Expo 1967 Netherlands Pavilion (Montreal)
U2 - Expo 2010 Hamburg Urban Pavilion (Shanghai)
U3 - Expo 1970 Netherlands Pavilion (Osaka)
V2 - Expo 1970 Italy Pavilion (Osaka)
V3 - Expo 1967 Man The Explorer Theme Pavilion (Montreal)
X1 - Expo 2010 Innovative Tours Theme Pavilion (Shanghai)
X2 - Expo 1967 Brewers Pavilion (Montreal)
X3 - Expo 1970 France Pavilion (Osaka)

12.4. Investigating subsets

The software implementation enables[251] a certain flexibility and ways to filter the pavilion classification data, as well as turning on and off classification set. In this subchapter we will explore if it is possible to simplify the proposed system.

In a first experiment we will reduce the number of classification sets from 16 to the best performing six. In a second experiment we will drop all classification of distinct building parts that are marked as *minor*. At the end we will look at n-tiles and if we can gain any insights from them.

12.4.1. Classification Set Subsets

It is no surprise that the 16 classification sets perform differently. Though some of them are interconnected. Sometimes they have mirrored peers in like the Angle-Plane and the Angle-View. Others, for instance the Tilt and Angle-View are related by the rational behind them.

We will first look at a pair that is conceptually disjoint, but complements each other: The Feature and Curvature classification sets. When we return to Figure 337 we can see that the reduction of the Periphrase to just the pair Feature and Curvature performs at 14.7% and is closer to the 10.7% then any single classification set; even Tilt which is at 17.7%.

The fact that they complement each other must be taken with a bit of caution as it might very well be rooted in the curation of the pavilions. Groups like Blob (F), Concave (G), Undulation (H) and Ufo (U), Bubbles (X) and Anticlastic (Z) are tailored towards exploring the Curvature set. Though only the groups Spike (B) and Spiral (Y) are tailored towards the Feature classification set. We draw a small speculative working hypothesis that buildings try to express a visual design by constraining them self to a few shape properties and try to avoid overload.

Figure 339 shows how the two classification set complement each other. Column wellCurvature ⓵ shows were a well integrated Curvature is particular weak or strong. Column wellFeature ⓶ does the same for Feature. We can observe that there are some groups were both classification sets perform well together like Concave (G) and Spiral (Y). We can observe how the Feature classification set performs well ⓷ across the groups Spike (B), Hidden Simple (C) Multiple (D). The Curvature classification set performs well ⓹ in the groups Concave (G), Undulation (H), Truncation Hole (S), Truncation Corner (T), Penetrate Boxes (U), Geometry (V) and Bubbles (X)

251 The software implementation always calculate the result based on the raw data without relying on intermediate detached persisted results.

#	Picto	Building	normal		wellSelect2 (5)		wellCurvature (1)		wellFeature (2)		zero	
Mean			10.7%	7.2%	14.7%	14.5%	20.0%	19.2%	19.9%	19.9%	21.3%	24.5%
1 A1			9.4	8.2	18.0	25.9	21.7	15.3	24.4	40.8	23.6	26.8
2 A2			8.9	12.8	23.0	25.2	38.9	46.2	27.2	38.6	20.5	21.9
3 A3			11.7	12.7	16.7	8.3	25.7	17.0	19.0	[illegible]	24.6	23.4
4 B1			9.0	10.4	13.2	13.4	41.0	41.0	11.1	[illegible]	23.3	28.5
5 B2			19.4	10.1	13.6	10.9	21.7	20.8	13.7	[illegible]	13.8	12.0
6 B3			9.0	9.3	7.8	5.9	21.5	27.7	8.8	[illegible]	22.7	24.0
7 C1			7.3	5.5	6.1	6.9	15.0	6.3	6.0	[illegible]	[illegible]	16.8
8 C2			14.0	6.3	15.9	9.0	28.9	9.0	7.3	[illegible]	28.8	33.2
9 C3			5.0	2.6	12.6	5.1	8.3	4.2	13.8	[illegible]	17.8	20.9
10 D1			11.6	7.7	9.2	5.8	36.8	53.7	8.5	[illegible]	18.1	25.9
11 D2			11.7	8.9	16.3	17.7	24.3	12.8	17.1	[illegible]	18.9	15.1
12 D3			9.3	5.4	17.3	20.2	18.6	24.8	17.3	18.1	20.2	20.6
13 E1			18.1	10.1	26.9	24.1	29.2	24.2	32.2	34.8	22.3	22.3
14 E2			18.1	15.8	21.8	27.7	16.4	27.1	34.0	41.7	25.4	23.1
15 E3			10.7	7.9	21.5	23.0	24.3	28.9	21.8	24.9	17.9	15.9
16 F1			8.9	9.3	16.9	26.4	20.4	28.3	26.5	25.9	25.1	27.3
17 F2			8.6	5.4	13.0	13.3	15.7	11.1	28.0	41.1	28.0	32.7
18 F3			9.2	12.1	26.1	30.4	23.7	30.2	31.2	25.6	23.5	22.4
19 G1			7.2	4.6	9.3	10.7	11.9	15.0	17.4	8.7	24.1	28.4
20 G2			8.4	4.8	10.0	5.3	8.7	[illegible]	8.2	3.7	11.2	11.1
21 G3			17.7	13.6	10.9	17.0	16.2	[illegible]	16.3	14.0	19.0	16.1
22 H1			13.6	5.9	12.8	12.7	13.1	[illegible]	36.0	28.6	24.6	28.1
23 H2			7.8	7.3	8.2	7.5	10.8	[illegible]	21.8	26.3	15.9	18.0
24 H3			6.1	3.8	11.1	10.1	11.6	[illegible]	30.7	32.4	20.9	22.8
25 S1			6.9	10.3	20.6	23.8	13.4	7.2	23.3	18.6	15.8	10.8
26 T1			6.7	4.6	14.0	5.1	11.2	7.6	21.0	5.1	23.0	34.8
27 U1			14.2	6.3	11.9	7.3	9.6	7.3	15.4	7.3	21.1	30.1
28 V1			7.2	0.1	15.3	23.7	14.4	21.1	17.7	25.9	19.6	19.4
29 W1			22.9	4.7	22.3	22.2	22.4	5.6	31.5	41.3	25.4	44.8
30 X1			9.0	1.8	7.0	2.0	12.4	7.0	24.2	26.7	20.2	32.6
31 Y1			5.5	0.2	11.0	6.6	14.6	17.0	13.7	3.9	21.6	29.3
32 Z1			11.3	1.0	14.0	6.0	20.6	6.0	11.7	6.0	24.0	41.4

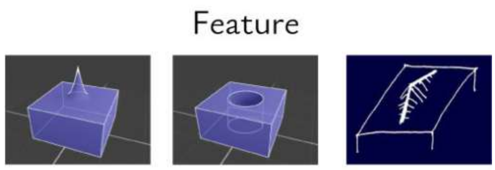


Figure 339: Impression of the effect of the Feature and Curvature classification sets. The numbers are faded out, so the complementing green areas can be better identified.

It is a surprising observation that the Curvature classification set does not perform well at the Blob (F) curated group. Though the overall results with all sixteen classification sets is still good for Blob (F). We can see that other classification sets like Angle-View, Angle-Plane, Edge-View and Edge-Plane amplify similar properties like Curvature and help to achieve overall good results for Blob (F).

Column wellSelect2 (5) shows the results when we use Feature and Curvature together.

We can repeat the experiment form the Feature and Curvature pair and expand it to six classification sets. Their selection criteria is that they perform better[252] then the reference Zero value. This reduces the count to a single Syntax Tree classification set and five Periphrase classification sets: Spacing, Tilt, Angle-View, Feature, Curvature and Edge-Plane.

The intention for this small experiment is to evaluate if it is necessary to apply all 16 classification sets. Computationally this is not a problem. But each classification set must be understood by the person performing the classification. A lower number would lower the entry barrier for participation and training.

Figure 340 shows the results of such an exploration. We can see that a "well integrated" setup with the six classification performs well with 12.0% (1a)[253] compared to the 10.7% (1b) of the full fledged system. Though we can observe, when the six classification sets are not "well integrated" the result falls to a weaker 13.3% (2). So concepts like Syntax Trees and Rules do provide their fair share. A pure tagging with keywords performs less good.

We can spot that in some cases like (3a) and (3b) the result is much better then the final result. This gives us a hint that a problem could be hidden in the slots of the skipped ten classification sets. We can also observe that the Hidden Simple (C) group does perform well in (4a) and (4b). This is a bit of a surprise as the composition is expected to be the driving force for their common identity.[254]

252 Better or at least on pair. This allows to include Edge-Plane which is only slightly above the reference Zero value.

253 Please ignore the technical term wellSelect3. It just hints that this is the third combination of classification sets that was tested.

254 We did not drop multiple Periphrases, Syntax Trees and Rules. Also the common Spacing item spacingContactPartial is present. The same arguments apply when we were discussing Hidden Simple with Figure 328.

#	Picto	Building	normal		noSelect3		wellSelect3		justSelect3		zero	
		Mean	10.7% (1b)	7.2%	16.6%	14.9%	12.0% (1a)	10.0%	13.3% (2)	12.6%	21.3%	24.5%
1 A1			9.4%	8.2%	13.1%	12.9%	10.9%	11.5%	14.7%	16.4%		
2 A2			8.9%	12.8%	12.6%	17.3%	20.5%	12.6%	35.4%	45.9%		
3 A3			11.7%	12.7%	12.8%	12.9%	20.3%	20.8%	28.9%	24.8%		
4 B1			9.0%	10.4%	20.0%	26.1%	10.1%	11.1%	15.3%	16.7%		
5 B2			19.4%	10.1%	22.6%	14.4%	16.7%	8.9%	14.0%	15.2%		
6 B3			9.0%	9.3%	21.3%	13.7%	9.6% (3a)	[illegible]	16.6%	9.7%		
7 C1			7.3%	5.5%	7.9%	6.8%	5.8% (4a)	[illegible]	5.3%	4.2%		
8 C2			14.0%	6.3%	16.4%	5.2%	11.8% (4b)	[illegible]	14.3%	9.0%		
9 C3			5.0%	2.6%	7.9%	6.8%	7.3%	4.4%	16.3%	14.3%		
10 D1			11.6%	7.7%	20.8%	23.2%	10.2%	4.2%	7.9%	4.7%		
11 D2			11.7%	8.9%	9.2%	3.9%	15.0%	21.1%	16.7%	26.1%		
12 D3			9.3%	5.4%	23.3%	30.3%	10.7%	8.7%	14.6%	11.1%		
13 E1			18.1%	10.1%	29.0%	23.1%	19.5%	14.3%	17.4%	14.3%		
14 E2			18.1%	15.8%	24.9%	21.3%	18.5%	25.2%	15.5%	28.9%		
15 E3			10.7%	7.9%	13.6%	11.2%	14.9%	14.0%	13.6%	12.2%		
16 F1			8.9%	9.3%	11.9%	11.2%	12.2%	12.5%	9.7%	11.1%		
17 F2			8.6%	5.4%	18.3%	10.4%	7.4%	3.3%	16.5%	14.1%		
18 F3			9.2%	12.1%	15.3%	9.8%	13.8%	17.4%	8.3%	11.3%		
19 G1			7.2%	4.6%	17.6%	7.4%	9.3%	7.5%	11.5%	9.8%		
20 G2			8.4%	4.8%	11.3%	10.4%	9.2%	4.2%	9.3%	2.8%		
21 G3			17.7%	13.6%	23.7%	15.7%	12.9% (3b)	[illegible]	13.7%	12.1%		
22 H1			13.6%	5.9%	15.5%	9.3%	12.0%	5.2%	12.5%	10.3%		
23 H2			7.8%	7.3%	13.1%	18.7%	5.7%	7.6%	7.8%	6.9%		
24 H3			6.1%	3.8%	12.0%	11.3%	6.4%	5.7%	7.9%	9.3%		
25 S1			6.9%	10.3%	15.9%	20.4%	11.2%	10.7%	13.4%	11.8%		
26 T1			6.7%	4.6%	10.4%	5.8%	5.5%	4.0%	7.3%	4.1%		
27 U1			14.2%	6.3%	16.0%	2.3%	15.1%	6.6%	10.0%	1.8%		
28 V1			7.2%	0.1%	13.9%	17.6%	13.7%	17.4%	10.6%	11.3%		
29 W1			22.9%	4.7%	29.1%	24.1%	22.7%	8.4%	15.9%	1.6%		
30 X1			9.0%	1.8%	11.9%	8.3%	11.8%	10.1%	9.8%	13.4%		
31 Y1			5.5%	0.2%	12.2%	5.5%	8.0%	4.8%	8.8%	7.8%		
32 Z1			11.3%	1.0%	27.9%	49.3%	11.0%	5.6%	12.7%	18.3%		

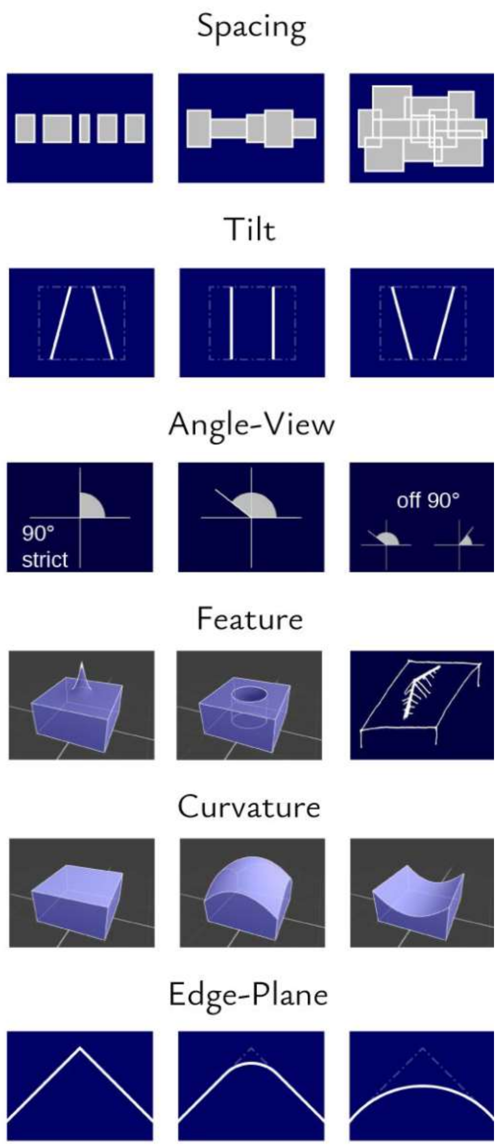


Figure 340: Result of the six best performing classification sets combined

12.4.2. Dropping minor composition branches

The initial creation of the 80 classification files was a labour intensive and technical process that resulted in 80 XML files of various complexity. This happened early in the research and of course without the future insights from the empirical results. Each building was mentally split up into parts. Then the decision had to be made if a part qualifies to be a distinct building part (See chapter 6.1). 24 pavilion contain distinct building parts that have made this threshold but then been marked to be of *minor* significance. In this section we will experimenting with leaving out these minor branches. Of the 24 pavilions, 14 pavilions would result in building shape that suddenly consist of s single Periphrase and no Syntax Tree[255]. They are depicted in Figures 341 up to 350[256] . The remaining ten pavilions have a setup with a bigger Syntax Tree. They will lose one branch.[257] Appendix A (19.1) contains multiple photographs per pavilions; this helps to spot the minor parts for some pavilions.

255 The 14 pavilions that will result in a single Periphrase are:
A2 - Expo 2010 Germany Pavilion (Shanghai)
C3 - Expo 1967 France Pavilion (Montreal)
E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)
E4 - Expo 2010 Saudi Arabia Pavilion (Shanghai)
E5 - Expo 1970 Switzerland Pavilion (Osaka)
E6 - Expo 1967 Quebec Region Pavilion (Montreal)
F2 - Expo 2010 Japan Pavilion (Shanghai)
F5 - Expo 2010 Aviation Pavilion (Shanghai)
G5 - Expo 1967 Italy Pavilion (Montreal)
H1 - Expo 2010 Chile Pavilion (Shanghai)
H3 - Expo 2010 Australia Pavilion (Shanghai)
S3 - Expo 1967 Czechoslovakia Pavilion (Montreal)
W3 - Expo 1998 Pavilion Of The Future Theme Pavilion (Lisboa)
Z3 - Expo 1970 Telecommunication Corporate Pavilion (Osaka)

256 excluding Figure 347

257 The 10 pavilions that will result in a lighter Syntax Tree are:
A4 - Expo 2010 Russia Pavilion (Shanghai)
D7 - Expo 1970 Bulgaria Pavilion (Osaka)
E7 - Expo 2010 South Korea Pavilion (Shanghai)
E2 - Expo 2010 China Host Pavilion (Shanghai)
G1 - Expo 1967 Soviet Union Pavilion (Montreal)
C1 - Expo 2010 Angola Pavilion (Shanghai) - See chapter 10.5 with Figures 277, 278 and 279
C2 - Expo 2010 Algeria Pavilion (Shanghai) - See chapter 10.5 with Figures 280, 281 and 282
C4 - Expo 2010 Monaco Pavilion (Shanghai)
C6 - Expo 2010 Croatia Pavilion (Shanghai)
C7 - Expo 2010 Sri Lanka Pavilion (Shanghai)
The last five pavilions of the “hidden simple” group will all lose “the porch”, while the identity towers are preserved. In chapter 10.5 we discuss and depict the impact of the Syntax Tree on the similarity of peers of the group. An overview of the group with photographs is in 12.1.3.

#	Picto	Building	normal		dropMinorComp	
		Mean	10.7%	7.2	11.5%	8.3
1 A1			9.4%	8.2	9.4%	8.2
2 A2			8.9%	12.8	10.4%	17.6
3 A3			11.7%	12.7	11.7%	12.7
4 B1			9.0%	10.4	9.0%	10.4
5 B2			19.4%	10.1	17.2%	10.2
6 B3			9.0%	9.3	9.0%	9.3
7 C1			7.3%	5.5	9.9%	11.7
8 C2			14.0%	6.3	14.8%	6.9
9 C3			5.0%	2.6	6.0%	2.5
10 D1			11.6%	7.7	13.1%	7.7
11 D2			11.7%	8.9	9.3%	8.9
12 D3			9.3%	5.4	9.3%	5.4
13 E1			18.1%	10.1	18.0%	9.4
14 E2			18.1%	15.8	17.9%	12.4
15 E3			10.7%	7.9	12.3%	7.5
16 F1			8.9%	9.3	8.9%	9.3
17 F2			8.6%	5.4	8.7%	9.5
18 F3			9.2%	12.1	9.7%	11.3
19 G1			7.2%	4.6	14.8%	10.8
20 G2			8.4%	4.8	8.4%	4.8
21 G3			17.7%	13.6	19.9%	19.6
22 H1			13.6%	5.9	10.5%	5.4
23 H2			7.8%	7.3	5.9%	7.3
24 H3			6.1%	3.8	14.1%	11.9
25 S1			6.9%	10.3	6.9%	10.3
26 T1			6.7%	4.6	8.5%	4.6
27 U1			14.2%	6.3	14.2%	6.3
28 V1			7.2%	0.1	7.2%	0.1
29 W1			22.9%	4.7	25.2%	5.6
30 X1			9.0%	1.8	9.0%	1.8
31 Y1			5.5%	0.2	5.5%	0.2
32 Z1			11.3%	1.0	11.3%	1.0

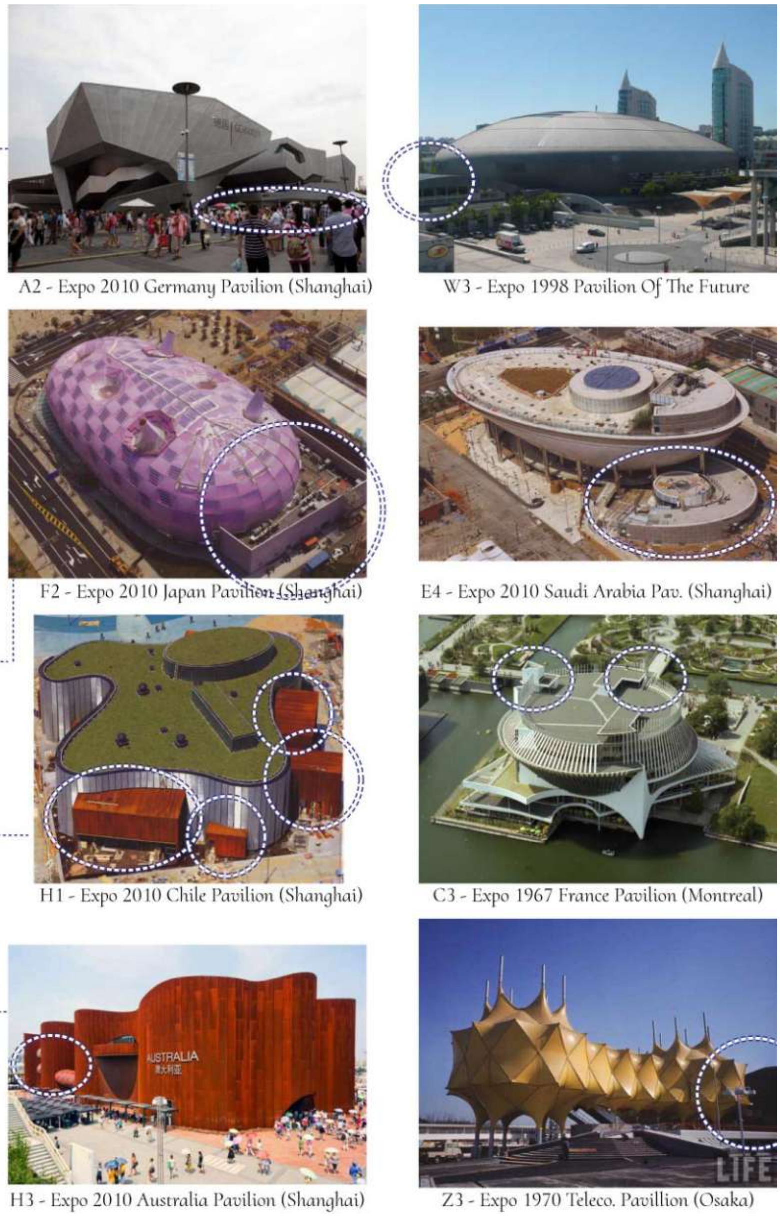


Figure 341: Table of results when Syntax Trees of minor significance would be dropped. To the right: 8 examples of building parts that would be dropped.

In Figure 341 we can see the effect of dropping the minor Syntax Tree branches. Column "dropMinorComp" has a value of 11.5% (1a). The unaltered setup scores the known 10.7% (1b). The penalty seems to be reasonable for the benefit of simplifying 24 classification files. The aggregated results are encouraging to drop minor distinct building parts. Though they are more ambivalent when drilling down to some individual pavilions.

H1 - Expo 2010 Chile Pavilion (Shanghai) (see Figure 341) and
H3 - Expo 2010 Australia Pavilion (Shanghai) (see Figure 341)[258] belong to the group Undulation (H). Still we see very different tendencies. While the Chile pavilion benefits from 13.6% to 10.5% (4), the Australia Pavilion looses from 6.1% to 14.1% (5). The dropping of the penetrating boxes from Chile pavilions keep the classification data focused on the curvatureUndulationWaves. Though the reduction of the Australia pavilion to just one Periphrase seems to drift it away from four peers in the curated group, which contain a

258 For the Austria Pavilion see also Figures 309 and 310 and the related discussion in 12.1.5.

Syntax Tree. The dropped spiral has related Curvature and Edge and Angle classification items to the main hall.

C3 - Expo 1967 France Pavilion (Montreal) has a big Syntax Tree with only minor significance branches. Removing the spike tower, balcony tower and base does not impact the result to much, as the main distinct building part has a strong classification itself.

Figure 342: E6 - Expo 1967 Quebec Region Pavilion (Montreal)

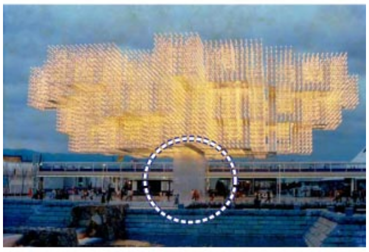


Figure 343: E5 - Expo 1970 Switzerland Pavilion (Osaka)

Figure 344: E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)

E3 - Expo 1967 Kaleidoscope Pavilion (Montreal) is our canonical example. We see that it drops from 10.7% to 12.3%. It is in the curated group Cantilever (E) together with E5 - Expo 1970 Switzerland Pavilion (Osaka) (see Figure 343) and E6 - Expo 1967 Quebec Region Pavilion (Montreal) (see Figure 342). By leaving out the base in these three pavilions and therefore making the Syntax Tree obsolete we erase a lot information which they have in common. The common spacingContactPartial, orientationVertical-Down and card2. We reduce it to just a cylinder for the Kaleidoscope and just a cube for the Quebec pavilion. The reason why they are still related by the software is the Periphrase level tiltViewFromBelow.

Figure 345: G5 - Expo 1967 Italy Pavilion (Montreal)

Figure 346: S3 - Expo 1967 Czechoslovakia Pavilion (Montreal)

Figure 347: G1 - Expo 1967 Soviet Union Pavilion (Montreal)

Figure 348: F5 - Expo 2010 Aviation Pavilion (Shanghai)

Figure 349: F5 - Expo 2010 Aviation Pavilion (Shanghai)

Figure 350: F5 - Expo 2010 Aviation Pavilion (Shanghai)

F2 - Expo 2010 Japan Pavilion (Shanghai) is from the Blob (F) group (see Figure 341). The dropping of the auxiliary part has little effect ❸. For this pavilion we might argue, that is was an unnecessary decision to model the auxiliary.

F5 - Expo 2010 Aviation Pavilion (Shanghai) is also from the Blob (F) group but the situation is more ambivalent. Figure 348 up to 350 show various views. While we can argue that the dome can be neglected, the mushroom structure on the opposing side is more prominent from a pedestrian perspective.

E7 - Expo 2010 South Korea Pavilion (Shanghai) has a similar problematic set up where "the wheel" would disappear (see Figure 351). The Korea pavilion is a large pavilion.[259] The wheel is part of the design idea to get inspiration from the unique Korean alphabet Hangul (El-Khoury, Payne and Riera Ojeda, 2010). The wheel is at one of the less frequented sides of the building. The other parts of the Korea pavilion are described very differently in the proposed classification system. The Korea pavilion is one of the buildings that is challenging for the proposed classification system.[260]

A4 - Expo 2010 Russia Pavilion (Shanghai) has its exhibition hall marked as *minor significance*. The main volume of the building would disappear.[261] (see Figure 352). This also happens to the already discussed base of the E2 - Expo 2010 China Host Pavilion (Shanghai)[262], and to some lesser extend in D7 - Expo 1970 Bulgaria Pavilion (Osaka) (see Figure 353). Especially these cases make it questionable if this experiment is valid. Though the straight forward solution here is to decide that these distinct building parts of *minor significance* should be lifted to *normal significance*.

Figure 351: E7 - Expo 2010 South Korea Pavilion (Shanghai)

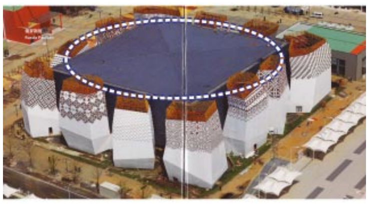


Figure 352: A4 - Expo 2010 Russia Pavilion (Shanghai)

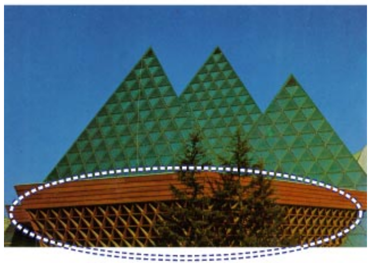


Figure 353: D7 - Expo 1970 Bulgaria Pavilion (Osaka)

Possible future additions to the 80 World Exposition pavilions will be classified with the knowledge acquired in this thesis. So decisions about distinct building parts and minor significance branches in Syntax Trees can benefit from these insights.

259 See the nine photographs of the pavilion in the Appendix A (19.1), to get an impression of its visual appearance.

260 The Korea pavilion will also be mentioned in the discussions/findings in chapter 13.4.

261 We discussed the Syntax Tree of the A4 - Expo 2010 Russia Pavilion (Shanghai) in detail in chapter 8.3.

262 We discussed the distinct building parts of E2 - Expo 2010 China Host Pavilion (Shanghai) in chapter 6.1. The base is visible in Figures 42 and 43.

12.4.3. Thirds

The last exploration with subsets focuses on n-tiles. It is possible to group all calculations for a curated group like Faceted (A) into thirds[263]. The result can be aggregated and visualised for all 32 pavilions with enough statistical data.

Figure 354 gives a visual explanation and a first impression of the results. The overall system performs with the well known 10.7%. The first third is at 7.6%, the middle third 13.7% and the last third is at 11.0%. The system can predict the first results better then the other. Especially the middle is hard to predict.

We need to take into account the way we define and map the calculated data onto the empirical data.[264] We reuse the minimum and maximum values from the empirical data and spread the calculate data into this range. When the calculated data and the empirical data predict the same pavilion as the first rank, then this leads to "0% divergence/perfect match" instance. Obviously these 0% are easier to achieve for the first rank and for the last rank. So the result of the n-tiles exploration must be consumed cautiously.

One shallow insight that we can draw is: the system is good at predicting the first ranks. This is useful from an application point of view. In many end user application like *search* and *exploration* the users will prefer navigation through the top ranked results similar to the result pages of a commercial search engine. In such an application the end user will most likely have little interested, why results in the middle or the end are not in a better order. A researcher of a classification system does of course care for all.

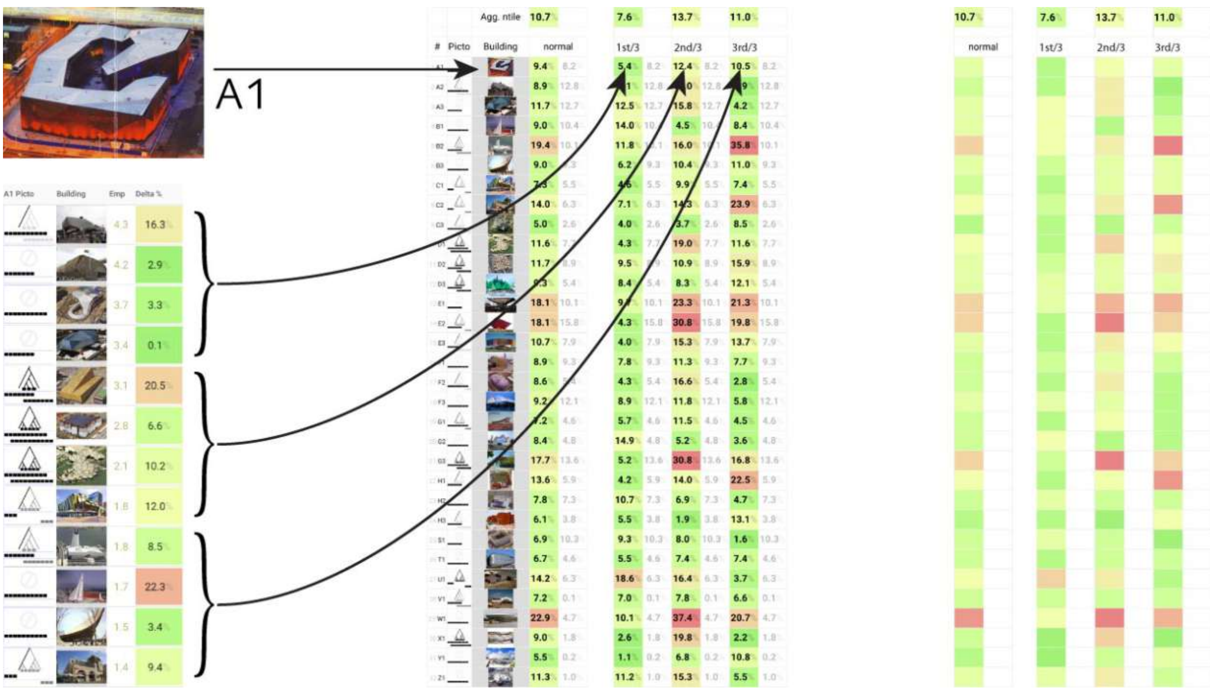


Figure 354: Explanation of the three thirds from the pavilion A1 - Expo 2010 Canada Pavilion (Shanghai) and where they appear in the aggregated table. To the right an impression of the table with the number values faded out

263 For instance the first four results for curated group Faceted (A)

264 See introduction of chapter 12, we discuss the upper and lower bound, as well as the definition of "Zero"

Part III

13. Discussion / Findings

13.1. Verification, Falsification

Is building shape classification effective?

As described in the introduction chapter 1.1 many architecture databases shy away from applying consistent building shape classification. Therefore we begin with a very simple question:

Is the building shape classification as introduced in this thesis better than just using a statistical mean value?

Yes, custom tailored domain specific vocabularies and their structured use have a positive effect.

The answer seems obvious and the statistical prove is discussed in chapter 12. Though the classification system introduced in this thesis has a certain level of complexity. Therefore it makes sense to look at each of its major building blocks in isolation as sub-hypothesis.

Additionally to the domain specific vocabulary (concept 1) there are: implicit statements (concept 2), lexicon and synonyms (concept 3) and syntax trees with recursive rules for the composition of distinct building parts (concept 4). We will first look at 2, 3, 4 and end with concept 1.

13.1.1. Sub-hypothesis: Implicit statements (concept 2)

Default values materialize implicit assumptions. There is no need to explicitly state them. The software system will fill the gaps and use them for further calculations. In the proposed system, the first use of this concept is in the *Periphrase*: when we do not state anything about the building shape, the software will assume that we are describing a cube shape which we call *perfect cube*. The second use is in the *Syntax Tree* for the composition layer: when we do not state anything about the composition of distinct building parts, then we assume that there are two of them, they are horizontal neighbours, and touch each other at one side without perfectly fitting the touching surfaces. This is the default composition. The theory of the concept is introduced in chapters 6.5.3 and 6.6.4, additional details appear in chapter 7.2 and the empirical findings are discussed in chapter 12.2.

Do implicit statements contribute in a positive way?

Yes, though there must be a consensus during the creation of new classifications for building shapes. There must be agreement about the default values. In this thesis there is only one author, which simplifies this task.

13.1.2. Sub-hypothesis: lexicon and synonyms (concept 3)

In Linguistics there is the idea of an in-memory lexicon. As humans, we can query this lexicon for words that we just heard or read. In the other direction humans can look for words to communicate a thought that we wants to express in a conversation. The matches in both directions are often not without ambiguity. In the incoming direction a word can have more than one meaning. In the outgoing direction we can express a thought with more than one choice of words. Synonyms might overlap in a generic context and still have a specialized meaning in a distinct context. The definitions are often not that sharp and this softness helps humans to express new thoughts and information about new situations while staying within a language framework. We assume that our conversation partner will be able to decode the fuzzy words based on the context. This is called *Pragmatics* in linguistics. It is even a symbol of culture and style when a speaker or writer is able to choose from a wide spectrum of words and synonyms to keep his readers attention. Tools like a thesaurus can help the writer as well as the reader.

As we see in the collection of World Exposition pavilions, we are encountering many building shapes that we might not have seen before. They have certain properties like for instance tilt, spacing or angles. The person that is creating new classification data for a building must decide if, for instance the angle of an important corner of a building is *strictly 90 degrees* or *kind of 90 degrees plus minus a few degrees.* Often this is in the eye of the beholder, especially when information is based on photographs rather than plan sketches. It is easier for authors to make such a decision, when they know that a backing system is not binary but rather a bit fuzzy and tolerant. So when authors choose "*kind of 90 degrees plus minus a few degrees*", they know that later queries that are searching *strictly 90 degrees* will also take these results into account. Even though this happens with slightly less emphasis and some penalty in the ranking.

From the other side, a consuming person that is in a kind of "exploration mode" might also not be as strict about the results. Having results ranked further down in a gradient fashion, instead of a strict black or white binary mode is what makes search engines different to strict databases. In this thesis the technical implementation of lexicon and synonyms is based on *Named Relationships* within classification sets. We call these relationships *Weak References*. It is introduced in chapter 9.3 and the empirical results are discussed in chapter 12.2.

Do *synonyms* in form of *Weak References* contribute in a positive way?

Yes, but the effect is less significant as anticipated by the author. Sometimes there are even negative effects within one classification set which are often compensated by the positive effects from Weak References of another classification set.

13.1.3. Sub-hypothesis: syntax trees with recursive rules for the composition of distinct building parts (concept 4)

During a first review of the World Exposition pavilions it quickly became obvious that some (53 of 80) – but not all – buildings are composed of more then one distinct building part. Composition of parts is present in architecture and a system that describes building shape should adapt to this use case. Such building shapes need some kind of rule set. The proposition from this thesis is the pair of *Syntax Trees* (see chapters 6.5 and 8) and *Recursive Rules* (see chapter 9.7.3). When such a rule set is absent then the pure quantity of classification items leads to serious outliers (see chapter 12.2).

Do Syntax Trees with recursive rules contribute in a positive way?

Yes. The positive contribution is bigger, when the focused building shape is a composed building shape itself. Thought it is also possible to observe positive indirect effects. In such circumstances the focused building shape consists only of a single Periphrase - but it is matched more precisely with parts of other composed buildings.

But; similar to their counterpart in linguistics the Building Shape Syntax Tree introduces some complexity. The software implementation as outlined in Appendix E (19.5), for this thesis is not covering 100% of what is described in the theoretical chapters. The author still likes to embrace the concept and sees potential in a full implementation and supporting authoring tools. Syntax Trees miss out a bit in the empirical part. This was not anticipated but the newly introduced *Periphrase* allowed to describe many building shapes *without* a Syntax Tree at all. Though when one drills down into the building groups that mainly contain composition, one can see a positive effect. Syntax Trees are effective where a building *ensemble* is defining the character of a building or when buildings are mainly composed of rectangular blocks. Rectangular blocks are widely used in buildings that are less exposed than World Exposition pavilions, so a different selection of buildings for the empirical data gathering would have shown more insight.

13.1.4. Sub-hypothesis: Domain specific vocabulary (concept 1)

Does a domain specific vocabulary have a positive contribution?

Yes. Custom tailored domain specific vocabularies have a positive effect. The positive effect of a carefully crafted vocabulary is not surprising. The vocabulary used in this thesis evolved during the research and had many fine tunings. The vocabulary as the sum of the items in each classification set plus the boundary condition that defines a member of such a classification set is hopefully as coherent as possible. Though it should be stated that there is no claim to have found the *perfect* vocabulary. Such vocabularies are tailored to their use case. For instance a "Classification of World Exposition Pavilions". A vocabulary to describe urban social housing or football stadiums would have slightly different areas of emphasis and omissions. Alternative approaches like the work from Lightweight Structures Research Unit (LSRU) (Sedlak, 1997) have their advantages as well. The LSRU vocabulary is especially well suited to describe lightweight and form-active structures where the shape is closely related to the structural system. Of course broadening the base that a vocabulary can cover is desirable and the author believes that the introduced vocabulary could be extended beyond pavilions. Maybe first incorporating further mostly free standing buildings like sport venues and then carefully extending it to denser urban context.

The vocabulary is dived into classification sets that are centred around a topic like Tilt, Curvature, Cardinality, etc. Many of these classification sets are custom tailored to the base assumption of the Periphrase: qualitative circumlocution instead of quantitative metric description. The move in the Periphrase towards qualitative items simplified many early obstacles and allowed faster progress. The empirical results are discussed in chapter 12.3. Next are some that stand out positively in the Periphrase:

- *Angle* in the view-orientation – A softer definition of angle than the strict geometric thinking (90 degrees) allows to describe certain architecture styles better. The different performance of angles in plane-orientation and view-orientation maps well to the insights from Vision research (Todd and Norman, 2003, p. 6).
- *Tilt* – Especially created for this thesis. It delivers the biggest positive contributions. It can also be well argued with knowledge from Vision research. At the same time it can be connected to certain architecture styles. It has the ability to describe widening shapes that are seldom in day to day buildings, but are a special design statement done by architects.
- *Curvature* – Allows to express *non-rectangular* building shapes. It is used without any quantifiers because various Vision research sources suggested that we as humans are not good to identify the quantity. For instance humans can recognize concave

objects very accurately but it is hard to distinguish quantities of concavity. The decision to omit any distinction of wall and roof for curvature must be seen as an embrace of contemporary architecture. In future research with more buildings this should re-examined and revalidated. It depends on the selected buildings.

- *"Feature"* – Is complementary to *Curvature* because buildings with flat surfaces tend to pick from this classification set. The terms of the classification items are backed by the "IL 22 form" book (Otto, 1988) .[265]

In the Syntax Tree and the composition layer we can point out:

- *Spacing* – It covers a complex topic and has a rich set of weighted relationships. The attribute pairs like contact vs. gap, matching vs. partial and linear vs. planar are intuitive.

The surprising underperforming classification set is *Proportions*. While an important topic in the architecture curriculum it is surprising to see that it does not contribute that much in similarity calculation. This might be routed in the use of *global* proportion on the overall building bounding box, rather than certain smaller elements with *local* proportions. The information from Vision research hints that humans might be less good at aspect ratio judgements. We can speculate, that we as humans know intuitively of this weakness and do not use it as a primary shape differentiator.

The look into cognitive disciplines like Linguistics and Vision have been very educative. It was a pleasure to read through works like Chomsky's Syntactic Structures, Jackendoff's Parallel Architecture, Lerdahl & Jackendoff's work on music, Biederman's Geons and Pizlo's radically different approach to shape.

It was surprising to find out that Vision is such a competitive field. One of the disputed topics that had direct impact on Periphrase was the ability – or inability – to perceive *quantitative* metric shape:

- Already the Gestalt psychologist leaned towards qualitative features.
- Biederman's Geons nearly completely neglect any quantitative features and even though they use patterns from geometry like generalized cones they stick with a qualitative terminology.
- The mainstream group around Todd is convinced that humans are weak at metric and aspect ratio: "vast majority of experiments on this topic is that judged metrical relations almost always deviate significantly from the physically specified structure, and they are often unreliable as well" (Todd and Norman, 2003, p. 14).

265 The "IL 22 form" publication is an effort of a lightweight structures team to describe all of nature, not only architecture (see chapter 5.4.2).

- Pizlo's approach concentrates on a few a priori constraints and gives emphasises to symmetry. He and his team claim that we have an innate capability to recognize symmetry. This focus reduces the importance of other topics, including metric features.
- Finally a more recent study confirms the positive results of qualitative features but sees the role of quantitative properties in a more positive light. "We found that given large perspective changes, observers were able to detect quantitative properties of objects to perform fast and accurate object recognition"[266] (Lee *et al.*, 2012, p. 8).

These statements give additional foundation to the classification sets that are used in the Periphrase. One group consisting of *Edge*, *Texture*, *Curvature*, *Feature* and *Lattice* does not include any quantifier at all and fully embraces the qualitative approach. The other groups of *Angle* and *Tilt* have a hybrid approach with both qualitative and quantitative. The last one is *Proportion* which only uses qualitative values with the golden ratio as a multiplier.

In the Syntax Tree the setup is a bit different because the binary tree structure allows a combination of qualitative sets like *Spacing* and *Orientation* be connected with quantitative like *Cardinality*, *Relative Size*, *Size Randomness* and *Variety*.

13.2. Efficiency and Effectiveness

A question arises if all 16 classification sets should be used?

Is it really necessary to fill out all 16 classification sets for each building shape and use all the four main concepts introduced in this thesis? The current insight is that the full blown software implementation with all classification sets is the best performing one in the empirical comparison (see chapter 12.2). Though the discussion of the result in chapter 12.3 and 12.4.1 shows that not all classifications sets are contributing evenly. There are six that are standing out. If a future stakeholder would see the results of just the six as sufficient, we could skip the others and be more efficient during the authoring of new classification data. We can further look at the results in chapter 12.2: when we *turn off* three of the four main concepts then, we can observe that the results are not dropping that much any more. A stakeholder might choose to just implement the concept of *implicit statement* (concept 2), which is a part of *Periphrase*, and then use a kind of tradi-

266 "In the 3D qualitative difference task, observers' recognition judgements were good in general for all differences of qualitative properties. Observers, however, discriminated objects better and faster as the difference in qualitative properties was larger (meaning objects had more qualitatively distinct features). [...] Thus, although large perspective changes were not necessary to recognize objects using qualitative properties, if information from large perspective changes was available, observers exploited this information to recognize objects more rapidly." (Lee *et al.*, 2012, p. 9)

tional tagging with the reduced keywords. The adapted saying: “A little bit of classification goes a long way” applies here well.

Once the pattern behind Syntax Tree is understood by new authors, they are able to create composition level data as fine grained as desired. It is possible to describe each and every annexe and hook it into a Syntax Tree. The point at which there is sufficient information added is up to the authors. They might focus on just some outstanding parts, or can try to describe the whole building, similar to the way we would create data in a Constructive Solid Geometry (CSG) based system. Often we would mark these annexe shapes as of *minor significance* for the identity of a whole building. The software then applies penalties to the information originating from such sub-branches. In chapter 12.4.2 we perform an experiment and turn off all these “minor significance” branches as if they would never have been added. The negative impact is within limits. A future stakeholder could be satisfied with the achievable result. As a rule, the stakeholder could advice authors to leave out any annexe building parts and therefore be more efficient during creation of new classification data.

The two above described measures would make authors of new classification data *more efficient*, but the question arises, if the resulting system is *less effective*. It depends. Effectiveness implies goal driven acting. When the goal is to create classification data for a vast amount of buildings, then the measures might be well justified. For instance for an existing bigger architecture database which is not solely focused on building shape. When the goal is to verify if the system introduced in this thesis is also valid for more and maybe slightly different kinds of buildings, then the above mentioned efficiency measure should be avoided. Especially a future software implementation of the statistics module, which is only described in theory here, could potentially leverage a lot from the Syntax Trees as well as from the quantity of classification sets.

13.3. Predictability and Stability

When we look at the ranked result lists like in chapter 12.4.3, then we can observe that it is easier to predict the first part of the result list than the second part. This insight should be taken with caution. In the preparation phase the World Exposition buildings have been curated by the author into groups that share something in common. In many cases this commonality is supported by the empirical data. Therefore many of the siblings of a group are often clustered at the top of the ranking, while buildings which have been added randomly to distract the participants are found in the second part. Still these are two positive effects. First the curated siblings are clustered at the front of the ranking. Second the ranking in between the curated siblings works out quite well. Often the top ranked computed building matches the one from the empirical data from the human participants. Surprisingly it is often also possible to predict the last ranked building. One could state that it is easier to predict what is black or white rather then the shades of grey in the middle. From a user point of view this is acceptable because in most goal focused tasks we are likely interested in the top ranked results rather than the tail. This expectation is similar to an Internet search engine, where we look through the first few search results and hardly look at later pages.

13.4. Further Observations

This section documents some observations which have not been in the focus of the empirical setup, but emerged as well.

Cancel Out

Due to the amount of data available, it is common to look at the results at a very aggregated level. These aggregated numbers represent statistical mean values. Though, unfortunately this level hides a lot of interesting details. A drill down, at least at the level of curated groups sometimes expose how the change of one parameter effects the ranking. Often positive and negative effects cancel out each other and result in only small changes in the overall mean value. Additional descriptive statistical values like mean distribution and variance can compensate, but sometimes interesting effects can only be found by exploration and gut feeling.

Only 80 Buildings

The decision to select 80 buildings for the classification work seems appropriate. This limitation allows that the data set is consistent and manageable. But during the theoretical work for the statistics module (see chapter 9.8) it became obvious that this number is too limited. The curated groups focus on certain themes, which make seldom things suddenly not so uncommon. Even though the curated group of *spherical buildings* was at the end not used in the empirical setup it nicely depicts the problem: Worldwide there are only very few spherical buildings like the Géode in Paris, the Epcot at Disney World or the “Kugelmugel” in Vienna Prater. But this shape is not uncommon on World Expositions because of its symbolic character. For instance there are: United States Pavilion at Expo 1967 in Montreal, Germany Pavilion at the Expo 1970 in Osaka, the symbol of the Expo 1982 in Sevilla, Romania Pavilion at the Expo 2010 in Shanghai and to some extend the egg shaped Malaysia Pavilion at the Expo 2015 in Milano. A similar problem exists in the other direction as well: on Expo 2010 in Shanghai there were dozens of Pavilions with a very similar shape. This is covered by the curated group “*hidden simple*” in the empirical data and discussed in chapters 10.5 and 12.1.3. But the empirical data only contains five of these buildings, not dozens. So when the 80 buildings would have been used as the basis of statistical calculations – if something is rare or common – this would have lead to flawed results. The five spherical buildings would have been as common as the dozens of "*hidden simple*" buildings. This problem lead to the decision to skip a software implementation of the statistics module.

Intended Complexity

On some occasions the architects of a pavilion decided to use complexity and shape diversity as a design theme of their contribution. One such example is the Korea pavilion on the Expo 2010 in Shanghai (see Figures 355, 356 and 357). The intent of the architects (El-Khoury, Payne and Riera Ojeda, 2010) was to use the Korean alphabet Hangul as an inspiration. In such cases the building shape classification introduced in this thesis can not cope well with the building shapes. Classification is often the description of a simplified model of reality. When the task of creating this simplified model introduces to many ambiguities, the results are less satisfying. For instance the Korea pavilion consisted mostly of spatially packed rectangular volumes. This part could be described well with the Syntax Tree. But there is also a huge horizontal cylinder as well as a few 45 and 60 degree tilted parts that significantly cantilever at prominent positions of the buildings.

Figure 355: North facade.
E7 - Expo 2010 South Korea
Pavilion (Shanghai)

Figure 356: West facade.
E7 - Expo 2010 South Korea
Pavilion (Shanghai)

Figure 357: South and East facade.
E7 - Expo 2010 South Korea
Pavilion (Shanghai)

Technical Progress

The analysis with photographs of past World Expositions has been a rewarding journey through architecture history and fashions. We discuss at the end of chapter 7.2 and in chapter 11.1 that it is considered acceptable by Vision researchers to use normal 2D photographs of objects to recognise and reason about their shape. There is a constant technical progress in capturing and visualising data. On the capturing side the creation and clean up of massive laser scan data sets becomes easier. Stereoscopic cameras that shrink in size and drop in price and the accompanying software like the Tango project from Google also contribute towards a solution. Both measurement technologies can – to some extend – be used with drones that allow to create aerial images at affordable costs. These technologies allow the creation of building shape geometry data in retrospective. On the visualisation side virtual reality headsets (VR) and augmented reality headsets (AR) are becoming available as well. This might impact data gatherings like the one performed in 2015 for this thesis. In the future, it will becomes interesting when participants might see the buildings stereoscopic in 3D. Maybe even constraint to just pedestrian perspectives like in the real world. But we can not rewind time. It is actually to late for most World Exposition pavilions, because these buildings were mostly temporal and are already demolished. There is a certain bitter irony in this. World Exposition pavilions and sites are perfect (because they turn off so many other architecture aspects) and then again imperfect because they disappear.

13.5. Explanation and/or Description

This thesis is using *human judgements* at some important points. The classification of the 80 World Exposition buildings has been done by the author and can therefore not be 100% objective. It is biased to a certain degree. The decision if a wall should be classified as *normal tilt* or some *significant tilt* is blurry. It is further limited by the fact that most buildings have been classified based on photographs rather than from experiences on site. While these limitations are unfortunate, it is currently one of the available compromises to cope with the topic building shape that is not as broadly researched. Buildings are different to other things as they are expensive to erect, are bound to building sites and might be spread around the world. The World Exposition pavilions are additionally bound by time and most of them are deconstructed after the event finishes.

As this thesis is using some inspirations form the cognitive sciences it might be worth while to see how these sciences are viewing the rise of *probabilistic statistics* and *machine learning*. These trends are fuelled by the technical advances to crunch more and more input data. This section discusses how the contributions of this thesis can be seen in the context of these trends within some of the associated sciences. First we will have a brief introduction what the trends are and then how they affect this thesis.

There are roughly three groups in Neuro sciences and Cognitive sciences[267]:

- The "Why/Internal(?)" Group – These are researchers who build upon the theories and patterns often from times when access to computing resources was limited. They are hoping to find computational models that are lean, logical and elegant. They assume that the human brain wants to be as efficient as possible. Generative Grammar Linguistics and the Vision research as defined by the Marr paradigm are within this group.
- The "How/External(?)" Group – Especially with current trends of the last decade in Artificial Intelligence and Computer Science there are new possibilities to have access to massive amounts of empirical data as well as to an ever evolving computing power that can process this data. Machine Learning, Predictive Analytics

267 Of course this is an over-simplification, but should be acceptable to give an overview just for the following discussion on *probabilistic statistics*.

and Linguistics programs like Probabilistic Context-Free Grammar (PCFG) are within this group.

- A third group tries to position themselves pragmatically in the middle and benefit from both directions. They are sometimes referenced as *hybrid* approaches.

The current engineering and conceptual progress in the "How" group triggered a discussion about the way Neuro science and Cognitive science define success. Within the "Why" group there are approaches where researchers are looking for *explanations, insights* and the *internal structure* of a system. On the other side there are researcher that use probabilistic statistics to better and better analyse the past and make *predictions* about the present and future. They work with the *external* association between past behaviour of a system[268].

In the field of Vision, researcher have not been able to prove yet that a human makes thousands of mental photographs of a shape like an animal in motion to remember the shape of that animal. There are curios problems with such an approach: we are able to recognize such an animal from a point of view we might have never seen it before. And it might be questionable if we are capable to store so many mental photographs for each and every objects that we encounter and remember. The current efforts in self driving cars are going down this *quantitative* route of millions of stored input images and videos. While the researchers in Marr's Vision are looking for lighter systems like the Biederman's Geons (see chapter 5.3.2) or a system based on a very limited and simple set of priori constraints where symmetry plays a central role. The goal from researchers like Pizlo is not to create a system that can statistically predict but it is aptly titled "Making a Machine That Sees Like Us"[269].

Also many researchers in Linguistics who concentrate on the mainstream idea of *Generative Grammar* can be seen within Marr's thought framework. This is certainly true

268 One of the academic events that show cases this discussion was the symposium called "150th anniversary of the Massachusetts Institute of Technology – Brains, Minds and Machines". It was intended to inspire multidisciplinary work by connecting the Artificial Intelligence with its origins. The penal discussion had leading researchers from computer science, psychology, biology and linguistics. Though the linguist Noam Chomsky has been critical about the way probabilistic statistics defines success . This triggered response by the lead researcher of the Google corporation Peter Norvig (2017). Norvig points out that in the last fifteen years in language science many researcher did the switch from logical rule based system towards probabilistic systems because they personally saw a lot of limitations in the former and benefits in the new.

269 Pizlo is described as in opposition to the Marr paradigm in chapters 5.3.4 and 8.4. This is true for important parts, though he is still in the broader Marr tradition where he aims for a system that can explain and give insights into the internal human system. Pizlo is particularly sceptical about the role of learning in the veridical shape recognition (Pizlo *et al.*, 2014, p. 20). He points out that the system that he proposes uses innate a priori constraints and therefore is independent from any learning task (Pizlo *et al.*, 2014, p. 207). "Why should learning play any role in 3D shape perception if 3D shape can be recovered from the two-dimensional visual input without learning? It seems simpler, and much more parsimonious, to assume that these constraints are built-in, as well as effective. [...] Learning is superfluous." (Pizlo *et al.*, 2014, p. 70)

for the prominent proponent Noam Chomsky (Katz, 2012) and also people like Ray Jackendoff can be positioned here. Chomsky does honour the *engineering success* but criticizes that the kind of scientific success, that is defined how accurately the world can be modelled from external observations, is different to the success which tries to provide insights into a system[270]. In his response Norvig emphasises that this kind of success is not novel at all, if one looks at science in general and that there is scientific progress which leads into significant engineering progress by using the probabilistic route[271]. Norvig argues there are good arguments for both techniques and they traditionally coexist in science. No side of the arguments questions statistics in general, and it is a tool to validate scientific models of all kinds. Though the emphasis of just probabilistic statistics is discussed.

Norvig (2017) points out that there are also successful *hybrid* systems. They use smart elegant internal structures and combine them with statistical models gathered from empirical data to achieve better results. This pragmatic approach could also be used in building shape classification.

The concepts of Building Shape Periphrase and Building Shape Syntax Trees are certainly attempts to model a smart and lean rules based system. But as discussed in chapter 9.8 one additional rule for ranking building shape similarity could be the *statistics module*. It would boast combinations which are seldom and penalise combinations which are common. This would introduce a part of a *hybrid* system for building shape classification.

Beside of the academic discourse discussed above this thesis must also be seen in a technical implementation point of view. This thesis was completed in 2021 and should be seen in the technical and scientific context of that time. There is currently a strong trend that *machine learning* is taking the leap from a mainly scientific topic towards an applied IT industry topic. This trend is driven by the military industry and things like self driving cars as well as smarter algorithms to serve needs of applications like photo sorting where a user base is counted in the hundred of millions. To set up a machine learning system one ideally requires a huge amount of a priori empirical data. So the algorithm can learn against a training data set and then be verified against a validation data set. The potentials to make use of the now broader available machine learning software have been considered at the beginning of this thesis, but then the decision was made to omit them.

270 The interviewer Yarden Katz summarised Chomsky's positions as following: "Chomsky argued that the field's heavy use of statistical techniques to pick regularities in masses of data is unlikely to yield the explanatory insight that science ought to offer. For Chomsky, the "new AI" – focused on using statistical learning techniques to better mine and predict data – is unlikely to yield general principles about the nature of intelligent beings or about cognition." (Katz, 2012)

271 Norvig states: "language is not an eternal ideal form, represented by the settings of a small number of parameters, but rather is the contingent outcome of complex processes. Since they are contingent, it seems they can only be analyzed with probabilistic models." (Norvig, 2017)

There are several reasons that back this decision:

- The author did not have access to any source that would deliver a data set that would be big enough to serve as a base for the machine learning set. The topic of building shape is currently not widely represented as discussed in the introduction. World Exposition pavilions have some important advantages (see chapter 6.3.1) and no accessible existing source focused on them.
- New buildings that never had been seen must have a way how they are added to the system. This is similar to the recommendation frameworks available today. If we add a smartphone to an online shop and it should appear in recommendation we must give it at least some anchor points like brand, price range, physical size, camera specs, or some other technical features. So we need to give the system classification items. This thesis might be seen as a foundation work that delivers these classification sets in the first place. Still a machine learning system needs to reinforce this start position with new empirical data, so the new building / smartphone must generate empirical data. This constant creation of new empirical data is challenging in an academic setup.
- Machine learning based on training sets has the problem that it often emphasis the commonly known and filters away the special or novel aspects. So a *fair* training data set must already contain most of the known building shapes which makes it even harder to start with. Especially in a field that often aims to create new building shapes, or transform and evolve existing ones.

The *human judgement* as mentioned in the first paragraph of this section should be seen in the “Why/Internal” tradition. Similar to the efforts in Generative Grammar and Marr’s Vision. The goal in this thesis is to find a smart, lean and elegant system that is efficient for the task at hand. In this effort insights came from observation, reasoning and analysis and are validated against empirical data. Ideally future researchers can build upon this foundation and reinforce or fine tune the system by more backing empirical data and further observations and reasoning.

The analogy with linguistics and Generative Grammar stands as such: Just speaking out loud a few sentences is always easy and the normal speaker does not care if there is an underlying binary tree structure or something similar. When told that there might be such and such hidden structure it might look intimidating and unnecessary complex. From a logical and computational point of view these structures are actually not very challenging. Though one should point out that thousands of Linguists are actively researching this topic and have not found satisfying explanations for many phenomena. So looking at a building as a user of it and looking for the building shape in isolation are two very different tasks. The first just needs our intuitive visual perception the second benefits from abstract classification and data structures like Periphrase and Syntax Tree.

13.6. Comparison

In chapter 3 we have pointed out previous 3rd party research efforts that deal with building shape. In this section we will review how the system introduced in this thesis relates to them in retrospective. For easier reading the system will be abbreviated as Building Shape Classification (BSC)

BSC differs from *Shape Grammar* and pure spatial model based approaches by not having a 2D or 3D representation at its core, but rather a linguistic structure that references 2D and 3D concepts in its vicinity. Collection and retroactive creation of compatible 3D content might become easier in the future but is challenging for existing complex buildings . This is especially true when there is limited access to original sources. This is where BSC might fill a significant gap. Stiny (2006) demonstrated that the use of *Shape Grammar* is not limited to architecture. When used within architecture *Shape Grammar* is sometimes used as an *analysis tool* like Mitchell (1990) demonstrated for the Palladian Villas. But it is also used as a *creation tool* of geometries for consumption by other applications. For instance to create realistic environments for computer games and movies. In such cases *Shape Grammar* is often used to generate common secondary buildings which surround the main spots. It can achieve this very effectively just by modulating parameters in between certain predefined ranges and within a predefined set of rules (Müller *et al.*, 2006). *Shape Grammar* can also be used as the base for parametric design and procedural design. In such cases the generated geometric building shapes are the primary focus. *Shape Grammar* is similar to BSC because it tries to create a smart and lean system and describe many shapes with it. Shape Grammar describes the whole geometry while BSC avoids exactly this by circumlocution in the Periphrase. BSC can not output any spatial data.

The *Fuzzy Shape* approach (Zhang, Pham and Chen, 2002) requires labour intensive work by humans to model the geometry in a 3D software. *Fuzzy Shapes* uses superquadrics as its geometric primitive. Superquadrics are not a mainstream modelling method nowadays but plugins for popular 3D modelling software suits are nowaday available. Though the modelling does not need to be that precise when one utilises the fuzzy shape database as a retrieval system. The fuzziness and therefore imprecision that allows exploratory search within such a retrieval system is based on 3D geometry. Modulation of its parameters that make up the algorithm that generates superquadric allows to associated different shapes and calculate a similarity value. In contrast, fuzziness is achieved in BSC by linguistic means and recursive rules. The creators of *Fuzzy Shapes* (Zhang, Pham and Chen, 2004) see the application of a fuzzy shape database in the creative design phase but do not focus on architecture itself, while BSC is tailored towards use in architecture. *Fuzzy Shapes* tries to create a smart and lean system to describe many shapes. Similar to *Shape Grammar* it describes the whole shape while BSC tries to avoid exactly that. Fuzzy shapes can be connected to Vision research with the work of Pentland (1986) and Biederman (1987) (see chapter 5.3.2).

Operative design (Di Mari and Yoo, 2012) can be seen complementary to BSC. The setup of BSC allows to introduce new classification sets alongside existing ones. This works in the Periphrase as well as the Syntax Tree. It might very well be, that for a data set different to World Exposition buildings, there are different properties that are more important. *Operative design* might be a provider of an additional *transformation* classification set for use in BSC. This new classification set is closer to the architecture mental model then purely geometry. Still *operative design* is primary about assisting architects and architecture students during the creative process. BSC is mainly documenting existing buildings.

Building Information Modeling (BIM*)* uses spatial data based on Constructive Solid Geometry (CSG) to describe a building shape while BSC uses human judgement as a method for creating building shape classification. This human factor might have its limitations and might not be 100% objective but the work has shown that the topic of building shape is not trivial. It will be interesting to see in the future if methods that are neither based on manual classification data nor on probabilistic statistics will perform. One such method is real 3D-model data comparison with spatial algorithms. Once the access to quality 3D data is solved this could become an option. Propagation of BIM and advances in scanning existing buildings might help to build up the data. Though there are interesting problems to solve for such efforts: For instance the China Pavilion at the Expo 2010 has a very iconic shape (see Figures 358, 54 and 55), but the base of the pavilion which houses most of the exhibitions is a huge flat slab (see Figures 55 and 56). This base is significantly bigger then the iconic tower but it is part of the building. A 3D-model based algorithm must do smart decisions and decide if the free standing Katimavik of the Expo 1967 is actually of similar shape or not (see Figure 359). BIM is not only about spatial data but at its core it tries to make spatial data smarter by allowing better parametric design and integration of life cycle data. This annotation data does not require to be spatial information. It might very well be knowledge captured as text or semi structured data. BSC could be represented as text or semistructured data and be integrated in a BIM of a building. BIM is focused around one real construction site, while BSC is about comparing building shapes. So the benefit of BSC in BIM will start to emerge when many BIM projects are annotated with the BSC data and make up a database. It might be a novel way to find construction solutions within past projects.

Figure 358: Pedestrian View. The grey base is part of the pavilion.
E2 - Expo 2010 China Host Pavilion (Shanghai)

Figure 359: "Katimavik"
E1 - Expo 1967 Canada Host-Pavilion (Montreal)

When we ignore the base of the China pavilion the two buildings in Figures 358 and 359 are related because they are dominated by an upside down pyramid. A clear geometric primitive is used as the design statement. A 3D similarity algorithm based on 3D data should be able to relate such buildings. BSC should also be able to infer this relation. Figures 360 and 361 show two buildings where the common element is not one clear geometric primitive, but rather the usage of faceted surfaces and irregular angles. BSC provides means were the person performing the classification can state that this shape property is significant for the *identity* of the building. Complex contemporary buildings where the design language might constitute itself in smaller shape properties might be easier to correlate in BSC than with 3D data based approaches.

Figure 360: Entrance of Pavilion
A1 - Expo 2010 Canada Pavilion (Shanghai)

Figure 361: Staircase of Pavilion
A2 - Expo 2010 Germany Pavilion (Shanghai)

14. Potential

A contemporary building can be seen as a creative answer to a complex question asked to the architect by owners, regulations, society, financial constraints, natural environment, etc. and the architects own design agenda. This is a hedge that Mitchell also places after introducing procedural rules for Palladian Villas (Mitchell, 1990). Stiny states that creativity and design can not be structured with a syntax at the beginning of a creative process. He proposes that it might be valid to use words “as a kind of retrospective summary of what I have done” (Stiny, 2006, p. 19)

Attempts to introduce *procedural architecture* into real world projects should respond to these concerns. The creative task is usually performed by a human architect who takes many aspects into consideration. Procedural architecture covers the creation process to various extend. Therefore it is exposed to these concerns. Building Shape Classification can omit this discussion because it focuses only on what Mitchell calls the *recognition* part and not the creation. Building Shape Classification is *a kind of retrospective summary of what was done.*

The Building Shape Classification introduced in this thesis should be seen as a foundation level contribution. But this foundation could serve as a base for potentially higher level systems and applications. Four possibilities are discussed next: (1) integration into an existing architecture database, (2) an academic research tool to find hidden relationships, (3) a solution finder for construction details, (4) a specialised World Exposition application.

(1) Integration

Integration into an existing architecture database would enable users to find relationships which might have been hidden or obfuscated previously. Existing architecture databases might already have classification data for topics like architects, engineers, material, structural system, epoch, style and geographic location. Having building shape as an additional facet in such a system would allow users to have a better *exploration mode*. Switching and combining multiple of these meta data options with building shape classification could make a user more efficient. Because the building shape classification is based on six up to 16 classification sets it might be interesting for a user to just concentrate on building shape for a while. One might turn some of the classification sets on and off and have for instance results based on *widening tilt* or *irregular faceted textures*.[272]

272 One of the challenges for such an integration would be to create a user interface for efficient creation of Building Shape Classifications for buildings that are still missing it. Ideally the higher level concepts (concept 1 up to concept 4) would be used as well. Such a software implementation should be possible. Current trends in software implementation favour loosely coupled systems with REST web service interfaces. This would allow to have a very custom tailored web user interface for the creation of the building shape part, and the main application could just present the building shape classification sets as

(2) Hidden Relationships

Lets take an analogy from linguistics: Seminal literature works like Goethes *Faust* might be out of scope to be generated by some computational framework. But syntax is a tool of linguists to find out if small parts like certain sentences in Faust apply to rules and might be compared to other sentences, maybe even from a different author. By stating that some book X and Faust use surprisingly similar sentence patterns one discovers a maybe previously hidden connection. This information can be handed over from the linguistics department to some literature department as a possible new insight which might trigger further case study based research. Ideally a Building Shape Classification could discover such relationships in architecture and hand them over to architecture theory to trigger further case study based research.

(3) Construction Details

A *construction detail solution finder* might be a potential application that is driven by more pragmatic needs rather than pure exploration and academic theory. If it would be possible to enrich the database with *material* and ideally *structural system* data one could have a novel way to find construction details. Construction details are often curated in book format focused on material. For instance a "Glass Atlas" or a "Concrete Atlas". These books usually contain dense content and they suffer from the physical limitation of printed publications. Not all construction details can be published at once and the presented construction details must be generic. A bigger company might already have a BIM repository of previous buildings with a lot of valuable construction details. Not all employees might be aware of all available data, which rests in such a repository. Building shape classifications sets like *Curvature*, *Edge* and *Tilt* together with material information might already be powerful filters. A query for a *timber* building shape that has an undulating curvature and is cantilevering might quickly lead to a small number of specialized construction details. When such a system is a company internal tool it might not only contain the CAD drawing but also some contact person, pricing information and internal notes. Access to high quality construction details is a competitive advantage so this kind of "solution finder" application would be more of a commercial project.

One of the weaknesses of Building Shape Classification might become a strength in such an application. Syntax Trees might have been used to not only describe the most prominent building shape but also less important annexe building parts. These parts might contain material (e.g. timber) information as well. When we have the task to solve a construction detail in a current project, we might be not very concerned that the found con-

---

text forms or ideally enriched by sketches and diagrams. The actual ranking could again be outsourced to the stand alone building shape server application. One challenging situation would be when the user starts to mix existing more coarse grained text based classification – for instance for material – with the more fine grained building shape meta data. In such a scenario the two ranked result lists must either be merged or the user interface could be presented as a *facet browser* which would simplify the integration.

struction detail comes from an annexe part of a previous building, as long as it helps in the current situation.

(4) World Expositions Application

A simple World Exhibition pavilion archive might also be a potential application of this thesis. This is driven be the fact that the author has gathered a lot of information about World Expositions in general and has visited some events (Expo 2000, Expo 2010, Expo 2015) and some former sites (Expo 1982, Expo 1998). Such a specialised archive might not be of mainstream use but could serve as an academic base to slowly expand the number of buildings with building shape data from the currently 80 to some more. This would allow to verify and further fine tune the findings from this thesis. Such a project could be managed by the author as a side project. The technical skills and personal interest are present. Though as every side project the time that can be invested in it might be more limited than anticipated.

The system could be web based and put special emphasis on a navigation that is focused around building shape. But it should be possible to add other faceted browsing concerns like: year, material, structural system, colour, size and costs. Being a specialised archive for World Exposition there might be some additional very specific meta data like:

- Country or organisation represented
- Political system (e.g. democracy vs. autocracy vs. dictatorship)
- Gross Domestic Product (GDP) of the commissioning country
- Economic progress (e.g. mature economy vs. emerging vs. underdeveloped)
- Cultural Zones (e.g. Occident & Orient, Asian & Western, Cold War blocks East & West)

This would allow to do queries like: Are the architects from the same origin as the commissioning country? For instance the gulf states often employ international architecture studios. Does this practise result in different building shapes?

15. Next Steps

Chapter 5 shows how Syntax Trees are influenced by the transfer of ideas and knowledge from linguistics. The linguist Jackendoff describes in his book “Meaning and the Lexicon: The Parallel Architecture” (Jackendoff, 2010) that tree structures and recursion are not limited to the syntax of sentences but might be the dominating computation structures of more human capabilities. For instance sentences are made up of phrases and words, which are assumed to be looked up in the human in-memory lexicon. Jackendoff proposes that the lexicon itself might be made out of these mostly binary tree structures as well. This idea would allow to argue that the human brain, or a computational model that tries to simulate it, needs to be efficient on just one single computational task: Recursive operations on a (mostly) binary tree.[273]

This thesis describes two concepts: Syntax Tree and Periphrase. The first one is obviously influenced by binary trees but the second one looks very “flat”. Though even the Periphrase can be represented in a binary tree form as discussed in chapter 8.4. Actually the software implementation is already capable to handle some of these deep trees. This part of the software was not utilized to keep the scope manageable. Conceptually it would make sense to integrate the yet omitted *Axes Distribution* classification set together with the *Symmetry* classification set on some of the Periphrase slots. For instance by emphasising that symmetry and multiple rotational axes are present in an *Edge* slot, one could better distinguish a strict cylinder from other more free form Building Shapes. The case that symmetry should be tighter integrated, can be argued by referring to the Vision researcher Pizlo (see chapters 5.3.4 and 8.4). In his contribution symmetry takes a central role. The impact of this conceptual addition for the empirical benchmark would most likely not be so big. This should mostly be done to complete the theory in the implementation. In the conclusion chapter of “Making a Machine That Sees Like Us” Pizlo et al (2014) connects his work also back to linguistics and hopes to provide further progress. It will be interesting to see what Pizlo and his colleagues will publish in the future.

Chapter 9.8 describes a statistical module which is not present in the software implementation yet. It would be an interesting addition. It would be possible to automatically mark single shape items – or combinations in a Syntax Tree branch – as *special*. Special can mean that it is a *seldom* combination and this could boast a certain similarity result. To have the statistical quantities one requires a bigger collection then 80 buildings. There are plenty more World Exposition pavilion that could be added to reach these quantities, especially from the more recent Expo 2015 in Milano.

Transparency and the use of void spaces are important tools for architects. Unfortunately this is one of the topics that was omitted due to the scope. Some World Expositions pavilions use glass to enclose other bigger shapes like huge spheres (Taiwan pavilion Expo 2010, Figure 79), organic structures (Belgium pavilion Expo 2010, Figure 80) or even nearly a whole hot air balloons (Lotte pavilion Expo 2012, Figure 81). A second kind of transparency is the use of bars and grids in very dense combinations to create gradient transitions between inside and outside (UK pavilion Expo 2010, Figure 82), (GS-Caltext pavilion Expo 2012, Figure 83), (Private Enterprise pavilion Expo 2010).

273 A dedicated publication on the lexicon is “The texture of the lexicon: Relational morphology and the parallel architecture” Jackendoff, R. and Audring, J. (2020). Oxford: Oxford University Press

To broaden the number of contributors of classification data it would be beneficial to create a specialized Graphical User Interface (GUI). This would also allow to verify if people apply the similar classification. We could test if there will be a consensus within a team, working to complete such a task.

Figure 304 describes the already gathered empirical data from the 52 participants. 24 of the participants have an architecture background, 14 have a civil engineering background and 14 have no direct connection to the building industry. By performing some more data gathering sessions and therefore adding some more participants, it could become possible to compare the social groups with each other. This might produce insights how the different groups judge building shape. Appendix C already exposes most data of the social groups[274].

As discussed earlier, there is currently an impressive progress in the Machine Learning community. The concepts are successfully moving from the academic realm into the applied engineering realm. This trend manifests itself in better and easier to understand Machine Learning software libraries. This also enables researchers in other fields to benefit from this progress. Researchers like the author are rather consumers of the ready made libraries and techniques. They are more interested in the result, rather then the Machine Learning algorithm. As discussed earlier the empirical data for building shapes might not be broad enough. Once the issue of data quantity is tackled it will be very interesting to compare the empirical data with the here proposed Building Shape Classification approach and a competing new Machine Learning approach.

274 This thesis only used the first column which does not discriminate the social groups and is also the most stable subset.

16. Closing Remarks

In a world where access to information becomes easier by the day, it becomes a challenge to handle the information overflow as well. For people working in architecture and the building industry this is an opportunity, because traditionally relevant buildings are spread hundred or thousand kilometres apart. Book publications are restricted to a curated selection. It is challenging to visit many of them in person. Progress in virtual reality technology and broader availability of spatial data will help. But even then, time is limited and people must decide which buildings to investigate. Architecture databases and their smart use of classification meta data should be able to help. The similarity calculation and various other filters will lead to rankings of buildings. The normal user is hardly interested in academic mean values and distributions, but will most likely want to dive down to individual buildings to learn something for the task at hand.

The Building Shape Classification introduced in this thesis is a foundation level contribution. But once integrated back with all the other aspects of buildings like structural system, material, epoch, architecture theory, buildings costs, user acceptance etc. it could be part of a powerful user friendly system to help to cope with the information overload.

In contemporary architecture sometimes “star architect” names are synonyms for certain building shapes. It might even appear that they actually *own* a certain building shape vocabulary. It might be refreshing to fade out this ownership and start searching in more unbiased ways. Still we should not completely reinvent the wheel and we should benefit from existing knowledge. Every additional perspective on big amounts of information is democratising the access and the interpretation a bit more. It allows the searching person to decide from one self if the right thing is found.

Back matter

17. Bibliography

The following bibliography listing contains the main sources used in the research. Please be aware that a smaller number of additional academic sources is referenced fully in footnotes. These are typically sources that: could not be accessed; are mentioned by other researchers but have not been review by the author; are encyclopedia references; or of minor significance. Additional sources appear in chapter "18 Image References"

Alexander, C. (1964) *Notes of the synthesis of form*. Paperback Edition 1971. Cambridge, Mass.: Harvard University Press.

Alexander, C. (1979) *The timeless way of building*. New York: Oxford University Press.

Alexander, C., Ishikawa, S. and Silverstein, M. (1977) *A pattern language: towns, buildings, construction*. New York: Oxford University Press.

Alexander, I. and Flagge, M. (2010) *Luxembourg Expo Pavilion 2010: Hermann & Valentiny and Partners*. Berlin: Jovis Verlag.

archINFORM (2015) *archINFORM -- International Architecture Database*. Available at: http://eng.archinform.net/index.htm (Accessed: 1 August 2015).

Arnheim, R. (1974) *Art and visual perception: a psychology of the creative eye*. Berkeley: University of California Press.

Bidese, E. (2002) *Die Strukturen des freien und kreativen Handelns : Interpretationen und Perspektiven aus der linguistischen Forschung Noam A. Chomskys und der ethischen Reflexion Thomas von Aquins*. Würzburg: Königshausen und Neumann (Epistemata : Reihe Philosophie ; 325).

Biederman, I. (1987) 'Recognition-by-components: A theory of human image understanding.', *Psychological Review*, Vol 94(2), pp. 115–147.

Brown, K. (ed.) (2006) *Encyclopedia of Language and Linguistics: V1-14*. Amsterdam ; London: Elsevier.

Chomsky, N. (1957) *Syntactic structures*. The Hague: Mouton (Janua linguarum, nr. 4).

Chomsky, N. (1980) *Sprache und Geist : mit einem Anhang: Linguistik und Politik*. 2. Aufl. Frankfurt/M.: Suhrkamp (Suhrkamp-Taschenbuch Wissenschaft ; 19).

Chomsky, N. and Foucault, M. (2006) *The Chomsky-Foucault debate: on human nature*. New York: New Press.

Critchlow, K. (1969) *Order in space*. London: Thames & Hudson.

Critchlow, K. (2011) *The Hidden Geometry of Flowers: Living Rhythms, Form and Number*. Edinburgh: Floris Books.

Culicover, P.W. and Jackendoff, R. (2005) *Simpler syntax*. Oxford; New York: Oxford University Press.

Debate Noam Chomsky & Michel Foucault - On human nature [Subtitled] (1971). Available at: https://www.youtube.com/watch?v=3wfNl2L0Gf8 (Accessed: 28 October 2019).

Deinhammer, A.-V. (2016) *Integrated evaluation of architectural design : the AQ-System - a morphological evaluation methodology of lightweight structures = Ganzheitliche Qualitätsermittlung von architektonischen Entwürfen : das AQ-System - eine morphologische Bewertungsmethodik von Leichtbaustrukturen, Integrated evaluation of*. Wien: Wien (Ganzheitliche Qualitätsermittlung von architektonischen Entwürfen das AQ-System - eine morphologische Bewertungsmethodik von Leichtbaustrukturen). Available at: https://permalink.catalogplus.tuwien.at/AC13235422.

Deng, Y. (2012) 'Shaping mega-event flagships: a case study of Expo Center of Expo 2010 Shanghai, China', *Facilities (Bradford, West Yorkshire, England)*. Edited by X. Zhang, 30(ISSN: 0263-2772), p. 610. doi:10.1108/02632771211270577.

Di Mari, A. (2014) *Conditional design: an introduction to elemental architecture*. Amsterdam: Bis Publishers.

Di Mari, A. and Yoo, N. (2012) *Operative design: a catalogue of spatial verbs*. Amsterdam: BIS Publishers.

Dickinson, S.J., Pentland, A.P. and Rosenfeld, A. (1992) 'From volumes to views: An approach to 3-D object recognition', *Directions in CAD-Based Vision*, *55*(2), pp. 130–154. doi:10.1016/1049-9660(92)90013-S.

Dövencioğlu, D.N. *et al.* (2015) 'Effects of surface reflectance on local second order shape estimation in dynamic scenes', *Vision Research*, 115, pp. 218–230. doi:10.1016/j.visres.2015.01.008.

El-Khoury, R., Payne, A. and Riera Ojeda, O. (2010) *States of architecture in the twenty-first century: new directions from the Shanghai World Expo*. London: Thames & Hudson.

Foucault, M. (1974) *Die Ordnung der Dinge: eine Archäologie der Humanwissenschaften*. 18th Edition 2003. Frankfurt am Main: Suhrkamp.

Gaß, S. (1990) *IL 25 - Form, Kraft, Masse: 5. Experimente / Siegfried Gaß*. Stuttgart: Krämer Verlag (Mitteilungen des Instituts für leichte Flächentragwerke (IL), Universität Stuttgart).

Getty Research (2015) *Art & Architecture Thesaurus*, *Art & Architecture Thesaurus (Getty Research Institute)*. Available at: http://www.getty.edu/research/tools/vocabularies/aat/ (Accessed: 2 August 2015).

Graham, R.L., Knuth, D.E. and Patashnik, O. (1994) *Concrete mathematics a foundation for computer science*. 2nd edn. Reading: Addison-Wesley, Massachusetts.

Hacken, P. ten (2007) *Chomskyan linguistics and its competitors*. Oakville, CT: Equinox.

Informationszentrum Raum und Bau (1981) *FINDEX Bau. Facettenartiges Indexierungssystem fuer das Bauwesen. Eine systematische Begriffssammlung zum Ordnen und Suchen von Bauinformationen*. Stuttgart: Informationszentrum Raum und Bau.

Isac, D. (2008) *I-language: an introduction to linguistics as cognitive science*. Oxford ; New York: Oxford University Press (Oxford linguistics).

Jackendoff, R. (2002) *Foundations of language: brain, meaning, grammar, evolution*. Oxford: Oxford University Press.

Jackendoff, R. (2007) *Language, Consciousness, Culture: Essays on Mental Structure*. 1st edition. Cambridge, Mass: MIT Press.

Jackendoff, R. (2009) 'Parallels and Nonparallels between Language and Music', *Music Perception: An Interdisciplinary Journal*, 26(3), pp. 195–204. doi:10.1525/mp.2009.26.3.195.

Jackendoff, R. (2010) *Meaning and the lexicon: the parallel architecture, 1975-2010*. Oxford; New York: Oxford University Press.

Jackendoff, R. (2017) 'In Defense of Theory', *Cognitive Science*, 41, pp. 185–212. doi:10.1111/cogs.12324.

Jackendoff, R. and Pinker, S. (2005) 'The nature of the language faculty and its implications for evolution of language (Reply to Fitch, Hauser, and Chomsky)', *Cognition*, 97(2), pp. 211–225. doi:10.1016/j.cognition.2005.04.006.

Jurewicz, P. (2005) 'Building shape ontology: organising, visualising and presenting building shape with digital tools (diploma thesis, Vienna University of Technology)'. TU Wien.

Jurewicz, P. (2015) 'Building Shape Syntax Trees: Linguistic Concepts for Architecture', in *Integrale Planung für Industrie-Bau 4.0. Industriebauseminar 2015*, Wien: Klein Publishing GmbH, pp. 66–78.

Katz, Y. (2012) 'Noam Chomsky on Where Artificial Intelligence Went Wrong', *The Atlantic*, 1 November.

Koenderink, J.J. *et al.* (2010) 'Does monocular visual space contain planes?', *Acta Psychologica*, 134(1), pp. 40–47. doi:10.1016/j.actpsy.2009.12.002.

Koenderink, J.J. and van Doorn, A.J. (1992) 'Surface shape and curvature scales', *Image and Vision Computing*, 10(8), pp. 557–564. doi:10.1016/0262-8856(92)90076-F.

Lee, Y.-L. *et al.* (2012) 'Object recognition using metric shape', *Vision Research*, 69, pp. 23–31. doi:10.1016/j.visres.2012.07.013.

Lerdahl, F. and Jackendoff, R. (1983) *A generative theory of tonal music*. Cambridge, Mass.: MIT Press.

Li, Y. *et al.* (2012) 'A tutorial explaining a machine vision model that emulates human performance when it recovers natural 3D scenes from 2D images', *Journal of Mathematical Psychology*, 56(4), pp. 217–231. doi:10.1016/j.jmp.2012.07.001.

Loh, S.K. (1989) *A vocabulary of shape and structure type in Australian applications of lightweight structures*. University of New South Wales.

Loh, S.K. (1996) *Typology of Shape*. Internal Report. Sydney: Lightweight Structures Research Unit, University of New South Wales.

Marr, D. (1982) *Vision: a computational investigation into the human representation and proceedings of visual information*. Reprint. New York: Freeman.

Marr, D. and Nishihara, H.K. (1978) 'Representation and Recognition of the Spatial Organization of Three-Dimensional Shapes', *Proceedings of the Royal Society of London B: Biological Sciences*, 200(1140), pp. 269–294. doi:10.1098/rspb.1978.0020.

 17. Bibliography

Martínez Calzón, J. and Castañón Jiménez, C. (2010) 'Weaving Architecture: Structuring the Spanish Pavilion, Expo 2010, Shanghai', *Architectural Design*, 80(ISSN: 0003-8504), p. 59. doi:10.1002/ad.1106.

Martínez Calzón, J. and Castañón Jiménez, C. (2013) 'Pabellón de España en la Expo 2010 en Shanghái - Spanish Pavilion for the Expo 2010 in Shanghai', *Hormigón y Acero*, 64(269).

Merriam-Webster, I. and Mish, F.C. (2011) *Merriam-Webster's collegiate dictionary*. Springfield, Mass.: Merriam-Webster, Inc.

Mitchell, W.J. (1990) *The Logic of Architecture: Design, Computation, and Cognition*. Cambridge, Mass: MIT Press.

Müller, P. *et al.* (2006) 'Procedural Modeling of Buildings', in *ACM SIGGRAPH 2006 Papers*. New York, NY, USA: ACM (SIGGRAPH '06), pp. 614–623. doi:10.1145/1179352.1141931.

Norvig, P. (2017) 'On Chomsky and the Two Cultures of Statistical Learning', in *Berechenbarkeit der Welt? Pietsch W., Wernecke J., Ott M. (eds)*. Wiesbaden: Springer Fachmedien Wiesbaden, pp. 61–83.

Otto, F. (1988) *IL 22 - Form: a proposal for developing a method of classifying and describing forms.* Stuttgart: Krämer Verlag (Mitteilungen des Instituts für leichte Flächentragwerke (IL), Universität Stuttgart).

Pentland, A.P. (1986) 'Perceptual Organization and the Representation of Natural Form', *Artif. Intell.*, 28(3), pp. 293–331. doi:10.1016/0004-3702(86)90052-4.

Perkins, D.N. (1972) 'Visual discrimination between rectangular and nonrectangular parallelopipeds', *Perception & Psychophysics Perception & Psychophysics*, 12(5), pp. 396–400.

Phaidon Press (2004) *The Phaidon atlas of contemporary world architecture.* London; New York, NY: Phaidon Press.

Phaidon Press (2015) *phaidonatlas.com -- Architecture for Architects*, *Phaidon Atlas*. Available at: http://phaidonatlas.com/ (Accessed: 1 August 2015).

Pinker, S. and Jackendoff, R. (2005) 'The faculty of language: what's special about it?', *Cognition*, 95(2), pp. 201–236. doi:10.1016/j.cognition.2004.08.004.

Pizlo, Z. (2008) *3D shape: its unique place in visual perception*. Cambridge, Mass.: MIT Press.

Pizlo, Z. *et al.* (2010) 'New approach to the perception of 3D shape based on veridicality, complexity, symmetry and volume', *Vision Research*, 50(1), pp. 1–11. doi:10.1016/j.visres.2009.09.024.

Pizlo, Z. *et al.* (2014) *Making a Machine That Sees Like Us*. 1 edition. Oxford: Oxford University Press.

Pottmann, H. and Bentley, D. (2007) *Architectural geometry*. Exton, Pa.: Bentley Institute Press.

Russell, S.J. and Norvig, P. (2009) *Artificial Intelligence: A Modern Approach*. 3rd edn. Upper Saddle River: Pearson.

Schaur, E. (1979) *IL 21 - Grundlagen: Form, Kraft, Masse ; mit einem Beitrag und einer Diskussion über das Ästhetische = Basics*. Stuttgart: Krämer Verlag (Mitteilungen des Instituts für leichte Flächentragwerke (IL), Universität Stuttgart).

Sedlak, V. (1996) *Structures Design Aid Database*. Sydney: Lightweight Structures Research Unit 1996-2001, Faculty of the Built Environment 2001-2005.

Sedlak, V. (1997) 'A Computer-Aided Conceptual Structural Design Aid', in. *1997 IASS Symposium 9-14 Nov 1997*, Singapore, pp. 745–754.

Stiny, G. (2006) *Shape: talking about seeing and doing*. Cambridge, Mass.: MIT Press.

Stiny, G. and Mitchell, W.J. (1978) 'The Palladian grammar', *Environment and Planning B: Planning and Design*, 5(1), pp. 5–18. doi:10.1068/b050005.

Todd, J.T. (2004) 'The visual perception of 3D shape', *Trends in Cognitive Sciences*, 8(3), pp. 115–121. doi:10.1016/j.tics.2004.01.006.

Todd, J.T. and Norman, J.F. (2003) 'The visual perception of 3-D shape from multiple cues: Are observers capable of perceiving metric structure?', *Perception & Psychophysics*, 65(1), pp. 31–47. doi:10.3758/BF03194781.

Wilson, R.A. and Keil, F.C. (1999) *The MIT Encyclopedia of the Cognitive Sciences*. Cambridge, Mass.; London: MIT Press.

Wittgenstein, L. *et al.* (1953) *Philosophical investigations*. 4th Edition 2009. Chichester: Wiley-Blackwell.

Wittgenstein, L., Russell, B. and Ogden, C.K. (2007) *Tractatus logico-philosophicus*. New York, NY: Cosimo Classics.

Wonka, P. *et al.* (2003) 'Instant Architecture', in *ACM SIGGRAPH 2003 Papers*. New York, NY, USA: ACM (SIGGRAPH '03), pp. 669–677. doi:10.1145/1201775.882324.

Zhang, J., Pham, B. and Chen, P. (2002) 'Modelling and Indexing of Fuzzy Complex Shapes', in Zhou, X. and Pu, P. (eds) *Visual and Multimedia Information Management*. Springer US (IFIP — The International Federation for Information Processing, 88), pp. 401–415.

Zhang, J., Pham, B.L. and Chen, Y.-P.P. (2004) 'A fuzzy shape database to support conceptual design', *Control and Cybernetics*, 33(1), pp. 141–172.

18. Image References

This research makes use of many photographs to discuss Building Shape Classification. This research is based on the academic fair use of the photographs. Care have been taken to reference the original sources. I like to apologise for any missed references or mistakes which might be caused by the sheer volume of the photographs.

There are multiple kind of photographs and diagrams taken from third party sources:

- Traditional use of figures and photographs from other research publications.
- 80 default photographs of the 80 World Exposition pavilions.
- Further photographs of the 80 World Exposition pavilions and further buildings in the main text document.
- Further photographs of the 80 World Exposition pavilions in the Appendices. Which have been used in the empirical data gatherings. (these are referenced in Appendix A)
- Sketches of classification items. These have all been created by the author.

We distinguish various use cases:

- When a diagram / image is from a publication which is also discussed in text, then a traditional Harvard style reference is used, which point to the “17 Bibliography”
- When a photograph origins from a print publication which was only used as a photography source then an inline reference is used.
- When a photograph origins from a volatile Internet source like a consumer photographs web site or a blog, then it is given a keyword like “<abc>” which is the dereferenced further below.

There are some Figures that show collages of multiple photographs. In such cases the use of a *comma* hints that this is not the only origin. When there is a rows and columns of photographs in a Figure, then the listing starts at the top right and continues like English language text flow.

Many diagrams and some photographs are created by the authors. The initials <PJ> are used in collages. When an image have been altered then the prefix “based on” is added. Many photographs have been cropped to serve the research purpose, so the focus on a single building.

 18. Image References

Referenced Images in Figures and Tables

Angle brackets like “<ArchivesdemontrealIcaAtomOrg>” are dereferenced further below. Light grey number like “VM94-EX265-133” should help to uniquely identify the photograph from a bigger collection. For Flickr sourced photographs the first part of the identifier is the part of the URL. For instance “7766428922_144da4f956_b” can be accessed as: https://www.flickr.com/photos/hollywoodplace/7766428922

When multiple photographs are used in a Figure, then the source are comma separated.

```
1: <ArchivesdemontrealIcaAtomOrg> VM94-EX265-133, <PJ> 1040708, <PJ> 1040772, <PJ> 1040746,
   <wikipedia>, <PJ> 1040460;
2: <ArchivesdemontrealIcaAtomOrg> VM94-B240-057, <PJ> 1040635,
   <ArchivesdemontrealIcaAtomOrg> VM94-EX136-089, <PJ> 1040415, <wikipedia>, <PJ> 1040671;
3: <ArchivesdemontrealIcaAtomOrg> VM94-EX265-133, <PJ> 1040708, <PJ> 1040772, <PJ> 1040746,
   <Flickr_userThePieShopsCollection> 7766428922_144da4f956_b, <PJ> 1040460;
4: <PJ> 1040692, <ArchivesdemontrealIcaAtomOrg> VM94-B220-064,
   <ArchivesdemontrealIcaAtomOrg> VM94-EX265-127, <PJ> 1040406,
   <Flickr_userThePieShopsCollection> 7766428922_144da4f956_b, <PJ> 1040351;
5: <ArchivesdemontrealIcaAtomOrg> VM94-EX265-133, <PJ> 1040708, <PJ> 1040772, <PJ> 1040746,
   <PJ> 1040719, <PJ> 1040460;
6: <PJ> 104077, <ArchivesdemontrealIcaAtomOrg> VM94-EX136-411, <PJ> 1040714,
   <Flickr_userMagstb67> erezCAN82PJ2 2718334696_fb4335085f_o, <PJ> 1040719, <PJ> 1040761;
7: based-of <Wikipedia-userWaitingxu>;
8: (Jackendoff, 2017);
9: (Jackendoff, 2010);
10: (Culicover and Jackendoff, 2005);
11: (Jackendoff, 2009);
12: (Lerdahl and Jackendoff, 1983);
13: (Lerdahl and Jackendoff, 1983)
14: (Marr and Nishihara, 1978);
15: (Marr and Nishihara, 1978);
16: (Biederman, 1987);
17: (Biederman, 1987);
18: (Pentland, 1986);
19: (Todd, 2004);
20: (Todd, 2004);
21: (Pizlo et al., 2014);
22: (Pizlo et al., 2014);
23: (Critchlow, 2011)
24: (Critchlow, 2011);
25: (Otto, 1988);
26: (Otto, 1988);
27: <SDA>;
28: <SDA>;
29: <SDA>;
30: <SDA>;
31: <SDA>;
32: <SDA>;
33: <SDA>;
34: <SDA>;
35: <SDA>;
36: <SDA>;
37: <SDA>;
38: <SDA>;
39: <SDA>;
40: <SDA>;
41: <SDA>;
42: <Flickr_userSteelersliu> 4893610612_4bdb000c5a_o;
43: <BingMaps>;
44: <Expo2010ShanghaiChinaFromTheAir> 120;
45: <CollectionscanadaGcCa> e000990843;
46: <PJ>;
47: <Flickr_userPetespix75> 4381419661_9e6baae671_o;
48: <Flickr_userExpomuseum> 4684914512_510197747a_o;
49: <Flickr_userSteelersliu> 4893608054_420b9fc5b2_o;
50: <Expo2010ShanghaiChinaFromTheAir> 019;
51: <Flickr_userMarcaurel> 5208134351_7788801c75_o;
52: <Flickr_userSteelersliu> 4893028885_570a394287_o;
53: <BingMaps>;
54: <Flickr_userSteelersliu> 4893610612_4bdb000c5a_o;
55: <Expo2010ShanghaiChinaFromTheAir> 115;
56: <BingMaps>;
57: <ArchivesdemontrealIcaAtomOrg> VM94-EX265-138;
```

 18. Image References

58: <Expo67NcfCa_byGilesClouatre> 2austria_3aae0fe66c;
59: <ArchivesdemontrealIcaAtomOrg> VM94-Bd1-046;
60: <PJ>;
61: <PJ>, thumbnails (80 pavilions);
62: <PJ>, thumbnails (600 pavilions)
63: <Flickr_userThePieShopsCollection> 7766428922_144da4f956_b;
64: <Life_byMichaelRougier> TimeLife_image_111339743;
65: <ArchivesdemontrealIcaAtomOrg> VM94-EX136-235;
66: <ArchivesdemontrealIcaAtomOrg> VM94-EX265-133, <PJ> 1040708, <PJ> 1040772, <PJ> 1040746,
<Flickr_userThePieShopsCollection> 7766428922_144da4f956_b, <PJ> 1040460;
67: <PJ> 1040692, <ArchivesdemontrealIcaAtomOrg> VM94-B220-064,
<ArchivesdemontrealIcaAtomOrg> VM94-EX265-127, <PJ> 1040406,
<Flickr_userThePieShopsCollection> 7766428922_144da4f956_b, <PJ> 1040351;
68: <wikipedia>;
69: <Flickr_userAnnamagal> 6201288571_73b79781b2_o;
70: <Flickr_userMarconunes> 3544119979_12bde35b9a_o;
71: <ArchivesdemontrealIcaAtomOrg> VM94-EX265-133, <PJ> 1040708, <PJ> 1040772, <PJ> 1040746,
<wikipedia>, <PJ> 1040460;
72: <ArchivesdemontrealIcaAtomOrg> VM94-B240-057, <PJ> 1040635,
<ArchivesdemontrealIcaAtomOrg> VM94-EX136-089, <PJ> 1040415, <wikipedia>, <PJ> 1040671;
73: <PJ> 1040764;
74: <PJ> 1040719;
75: <PJ> based on freely available clip art;
76: <PJ>;
77: <PJ>;
78: <PJ>;
79: <PJ> 1040047;
80: <PJ> 1040200;
81: <Panoramio_userPlumgarden_(54048)> 76697508;
82: <PJ> 1040733;
83: <Flickr_userSSchleicher> 7334127378_525bf5cd4c_b;
84: <Wikipedia-userUlomekFotoDe>;
85: <Flickr_userMarcaurel> 5208134351_7788801c75_o;
86: <Panoramio__user775448-brickl> 32940691;
87: <Expo2010ShanghaiChinaFromTheAir> 120;
88: <PJ>;
89: <Panoramio_user239280_(Baycrest)> 56967092;
90: <Expo2010ShanghaiChinaFromTheAir> 120
91: <Life_byCarlMydans> 06 TimeLife_image_5919616 IgGeZAB_XDFFXw;
92: <PJ>;
93: <Flickr_userKOota> 5798600785_f0040bc9e6_o;
94: <Panoramio_user(utf8)_(3705168)> 76721995;
95: <Life_byCarlMydans> 06 TimeLife_image_5919616 IgGeZAB_XDFFXw;
96: <PJ>;
97: <Expo2010ShanghaiChinaFromTheAir> 033;
98: <Flickr_userWojtekgurak> 5469176217_63aaf97127_o;
99: <ArchivesdemontrealIcaAtomOrg> VM94-EX264-012;
100: <PJ>;
101: <Flickr_userThePieShopsCollection> 7766428922_144da4f956_b;
102: <Expo2010ShanghaiChinaFromTheAir> 36b;
103: <Flickr_userWentaoYin12> 5550288856_e2bd91d58a_o;
104: <PJ>;
105: <Panoramio_user239280_(Baycrest)> 56967092;
106: <Expo2010ShanghaiChinaFromTheAir> 001;
107: <Flickr_userThePieShopsCollection> 5560908841_0cf4e19fa9_b;
108: <PJ>;
109: <PoltrackNet_byJohnPoltrack> USSRPavilion1970-20131114;
110: <CollectionscanadaGcCa> e000990839;
111: <PinterestArchitekturaPh> b4c2265c30e616368851ecc475585934;
112: <PJ>;
113: <PinterestArchitekturaPh> b4c2265c30e616368851ecc475585934;
114: <Flickr_userWentaoYin12> 5550288856_e2bd91d58a_o;
115: <Flickr_userWojtekgurak> 5466772900_2a9d7895b3_o;
116: <PJ>;
117: <CollectionscanadaGcCa> e000990864;
118: <Panoramio__user775448-brickl> 32940691;
119: <Flickr_userThePieShopsCollection> 5560908841_0cf4e19fa9_b;
120: <PJ>;
121: <PJ>;
122: <PJ>;
123: <PJ>;
124: <Flickr_userSteelersliu> 4893610612_4bdb000c5a_o;
125: <Expo2010ShanghaiChinaFromTheAir> 037;
126: <CollectionscanadaGcCa> e000990843;
127: <Flickr_userThePieShopsCollection> 7766428922_144da4f956_b;
128: based on <Flickr_userThePieShopsCollection> 7766428922_144da4f956_b;
129: <PJ>;
130: <PJ>;
131: <ArchivesdemontrealIcaAtomOrg> VM94-B208-021;
132: <Expo2010ShanghaiChinaFromTheAir> 033;
133: <Life_byCarlMydans> 06 TimeLife_image_5919616 IgGeZAB_XDFFXw;
134: <PJ>;

 18. Image References

135: <Expo2010ShanghaiChinaFromTheAir> 033;
136: <24621953AtIebryInfo_byTetsuo> 1323610946514132194 35_osak-ban-sen;
137: <Flickr_userThePieShopsCollection> 7766428922_144da4f956_b;
138: <PJ>;
139: <ArchivesdemontrealIcaAtomOrg> VM94-B208-021;
140: <Expo2010ShanghaiChinaFromTheAir> 036b;
141: <Flickr_userThePieShopsCollection> 3750276283_26d3059f98_b;
142: <PJ>;
143: <Flickr_userThePieShopsCollection> 7766428922_144da4f956_b;
144: <Expo2010ShanghaiChinaFromTheAir> 033;
145: <Expo2010ShanghaiChinaFromTheAir> 120;
146: <PJ>;
147: <ArchivesdemontrealIcaAtomOrg> VM94-B208-021;
148: <Flickr_userKOota> 5798600785_f0040bc9e6_o;
149: <Flickr_userThePieShopsCollection> 3750276283_26d3059f98_b;
150: <PJ>;
151: <Life_byCarlMydans> 06 TimeLife_image_5919616 IgGeZAB_XDFFXw;
152: <Expo2010ShanghaiChinaFromTheAir> 037;
153: <Flickr_userPicturenarrative> 4969950220_a311aae176_b;
154: <PJ>;
155: <PJ>;
156: <PJ>, thumbnails;
157: <PJ>, thumbnails, <Flickr_userThePieShopsCollection> 7766428922_144da4f956_b;
158: <PJ>;
159: <PJ>;
160: <Wikipedia_byJensBludau> Expo2000Japan;
161: <PJ>;
162: <PJ>;
163: <PJ>;
164: <Expo2010ShanghaiChinaFromTheAir> 036b;
165: <Flickr_userLizstless> 432849205_ad89edabfb_o;
166: <Panoramio_user(utf8)_(3705168)> 76721995;
167: <PJ>;
168: <Flickr_userWojtekgurak> 5469176217_63aaf97127_o;
169: <PoltrackNet_byJohnPoltrack> USSRPavilion1970-20131114;
170: <PJ> 1040415;
171: <ArchivesdemontrealIcaAtomOrg> VM94-EX265-138;
172: <StatesOfArchitectures_byNicLehoux> 2;
173: <Life_byCarlMydans> 09 TimeLife_image_5919617 5wGq4_mbmyE1lw;
174: <Flickr_userKOota> 5798600785_f0040bc9e6_o;
175: <Flickr_userLaurentBaudoux> 304876264_d01ed04101_o;
176: <Life_byCarlMydans> 06 TimeLife_image_5919616 IgGeZAB_XDFFXw;
177: <PJ>;
178: <ArchivesdemontrealIcaAtomOrg> VM94-EX136-235;
179: <Flickr_userSteelersliu> 4893610612_4bdb000c5a_o;
180: <Flickr_userDMorency> 2232247367_fc860653dd_o;
181: <PJ>;
182: (Dövencioğlu *et al.*, 2015);
183: <PJ>;
184: <Expo2010ShanghaiChinaFromTheAir> 167;
185: <StatesOfArchitectures_byNicLehoux> 2;
186: <Flickr_userChimaybleue> 4729950594_5e21978b54_b;
187: <PJ>;
188: <PJ>;
189: <PJ>;
190: <PJ>;
191: <PJ>;
192: <PJ>;
193: <Expo2010ShanghaiChinaFromTheAir> 120;
194: <ArchivesdemontrealIcaAtomOrg> VM94-B220-064;
195: <Expo2010ShanghaiChinaFromTheAir> 037;
196: <PJ>;
197: <PJ>;
198: <PJ>;
199: <CollectionscanadaGcCa> e000990843;
200: <Flickr_userBdutfield> 3090631217_878d1684bc_o;
201: <Expo2010ShanghaiChinaFromTheAir> 046;
202: <PJ>, thumbnails;
203: <PJ>, thumbnails;
204: <PJ>;
205: <PJ>;
206: <PJ>;
207: <PJ>;
208: <PJ>;
209: <PJ>;
210: <PJ>;
211: <PJ>;
212: <PJ>;
213: <Expo2010ShanghaiChinaFromTheAir> 037;
214: <Flickr_userExpomuseum> 4790090062_7ff92ee854_o;
215: <Flickr_userWojtekgurak> 5489885993_b657b7cc24_o;
216: <PJ>, thumbnails, <A4>;

18. Image References

217: <BingMaps>;
218: <PJ> 104077;
219: <Flickr_userSophieetfred> 5193796491_83f0c58159_o;
220: <PJ>;
221: <PJ>;
222: (Pizlo *et al.*, 2014);
223: (Pizlo, 2008);
224: <PJ>;
225: <PJ>;
226: <PJ> based on freely available clip art;
227: <PJ>;
228: <PJ>;
229: <PJ>;
230: <PJ>;
231: <PJ>;
232: <PJ>;
233: <PJ>;
234: <PJ>;
235: <PJ>;
236: <Expo2010ShanghaiChinaFromTheAir> 019;
237: <Expo2010ShanghaiChinaFromTheAir> 037;
238: <Expo2010ShanghaiChinaFromTheAir> 001;
239: <Flickr_userMarcaurel> 5208134351_7788801c75_o;
240: <Flickr_userSteelersliu> 4893028885_570a394287_o;
241: <BingMaps>;
242: <PJ>;
243: <PJ>;
244: <PJ>;
245: <PJ>;
246: <Flickr_userThePieShopsCollection> 7766428922_144da4f956_b;
247: <Life_byMichaelRougier> TimeLife_image_111339743;
248: <ArchivesdemontrealIcaAtomOrg> VM94-EX136-235;
249: <Expo2010ShanghaiChinaFromTheAir> 015;
250: <BingMaps>;
251: <PJ> 1040635;
252: <Flickr_userExpomuseum> 4674353294_798b6a0b6f_o;
253: <Flickr_userMeiguoxing> 4562528348_262feed030_z;
254: <Flickr_userGavinbloys> 5203599583_06f64ddfdb_o;
255: <Flickr_userThePieShopsCollection> 7766428922_144da4f956_b;
256: <Life_byMichaelRougier> TimeLife_image_111339743;
257: <ArchivesdemontrealIcaAtomOrg> VM94-EX136-235;
258: <ArchivesdemontrealIcaAtomOrg> VM94-EX265-127;
259: <CollectionscanadaGcCa> e000990853;
260: <ArchivesdemontrealIcaAtomOrg> VM94-EX96-031;
261: <ArchivesdemontrealIcaAtomOrg> VM94-EX264-012;
262: <Flickr_userDMorency> 2232247367_fc860653dd_o;
263: <ArchivesdemontrealIcaAtomOrg> VM94-B208-051;
264: <Flickr_userThePieShopsCollection> 7766428922_144da4f956_b;
265: <Life_byMichaelRougier> TimeLife_image_111339743;
266: <ArchivesdemontrealIcaAtomOrg> VM94-EX136-235;
267: <Flickr_userSteelersliu> 4893610612_4bdb000c5a_o;
268: <Expo2010ShanghaiChinaFromTheAir> 115;
269: <BingMaps>;
270: <Flickr_userChimaybleue> 4739748661_b595a6b843_b;
271: <Flickr_userExpomuseum> 4703260871_d06be3e75a_o;
272: <Flickr_userFrankschacht> 4999052652_c92e684c6e_b;
273: <PJ>;
274: <Flickr_userFrankschacht> 4663059809_26d8f763eb_b;
275: <Flickr_userKimon> 4691922765_26d9673878_o;
276: <Flickr_userGavinbloys> 5679031723_faf51d6206_o;
277: <Flickr_userWojtekgurak> 5417727359_865fc7ae6f_o;
278: <Flickr_userKimon> 4686486565_6519d11fed_o;
279: <BingMaps>;
280: <Flickr_userFrankschacht> 4997424655_73ecd09a48_b;
281: <Flickr_userFrankschacht> 4997488663_01f65a889f_b;
282: <BingMaps>;
283: <PJ>, thumbnails, <C1>;
284: <PJ>, thumbnails, <C2>;
285: <PJ>;
286: <PJ>;
287: <PJ>,
<ArchivesdemontrealIcaAtomOrg> VM94-EX243-048,
<Flickr_userLaurentBaudoux> 304876260_d67e90ffac_o,
<Flickr_userPetespix75> 4382588724_24b13009e3_o,
<ArchivesdemontrealIcaAtomOrg> VM94-EX130-001,
<UncubeMagazine_byShunkKender>
288: <PJ>, thumbnails, <E3>;
289: <PJ>, thumbnails, <pavAppendixA-E3>;
290: <PJ>, thumbnails, <pavAppendixA-E3>;
291: <PJ>, thumbnails, <E6> <E3>;
292: <PJ>, thumbnails, <pavAppendixA-E6>, <E3>;
293: <PJ>, thumbnails, <pavAppendixA-E6>, <pavAppendixA-E3>;

 18. Image References

294: <PJ>, thumbnails, <E3>;
295: <PJ>, thumbnails, <E3>;
296: <PJ>, thumbnails, <E3>;
297: <PJ>, thumbnails, <E5>, <E3>;
298: <PJ>, thumbnails, <pavAppendixA-E5>, <pavAppendixA-E3>;
299: <PJ>, thumbnails, <E3>;
300: <PJ>, thumbnails;
301: <PJ>, thumbnails, <E2>, <E3>, <E4>, <E5>, <E6>, <E7>, <E1>;
302: <PJ>, thumbnails, <E7>, <G2>, <E4>, <E2>, <E3>;
303: <PJ>, thumbnails, <E6>, <H3>, <E5>, <F3>, <E3>;
304: <PJ>, thumbnails, <E4>, <E6>, <E5>, <E2>, <H3>, <E7>;
305: <PJ>, thumbnails, <A1>, <A2>, <A6>, <A5>, <A3>, <A7>, <A4>;
306: <PJ>;
307: <PJ>;
308: <Flickr_userWojtekgurak> 5469176217_63aaf97127_o;
309: <Flickr_userWojtekgurak> 5469770110_ac5d1f23f2_o;
310: <Expo2010ShanghaiChinaFromTheAir> 007;
311: <Flickr_userExpomuseum> 4795272684_eb6f82a1b3_o;
312: <Flickr_userExpomuseum> 4795270648_d0219a0b0e_o;
313: <Flickr_userExpomuseum> 7836263826_7724ac7827_o;
314: <Flickr_userCesarCorona> 7167769559_6681accb96_o;
315: <Flickr_userHtglss> 7494162614_a7acbcaa23_o;
316: <Panoramio_userPlumgarden_(54048)> 76696978;
317: <PJ>;
318: <PJ>;
319: <PJ>;
320: <PJ>, thumbnails;
321: <TokyoskyTo> EXPO70;
322: <ArchivesdemontrealIcaAtomOrg> VM94-EX136-419;
323: <Flickr_userExpomuseum> 4684711554_41ddbdd0da_o;
324: <ArchivesdemontrealIcaAtomOrg> VM94-EX266-238;
325: <Flickr_userExpomuseum> 67823628_1f52ce12c9_o;
326: <ArchivesdemontrealIcaAtomOrg> VM94-EX136-167;
327: <CollectionscanadaGcCa> e000990859;
328: <ArchivesdemontrealIcaAtomOrg> VM94-B208-051;
329: <Panoramio__user775448-brickl> 32939643;
330: <Flickr_userKimon> 4686486565_6519d11fed_o;
331: <Flickr_userFrankschacht> 4997488663_01f65a889f_b;
332: <Flickr_userCesarCorona> 7167769559_6681accb96_o;
333: <Flickr_userKimon> 4633171163_a3dcc6b589_o;
334: <Expo2010ShanghaiChinaFromTheAir> 010;
335: <GoogleMaps>;
336: <PJ>, thumbnails;
337: <PJ>;
338: <PJ>, thumbnails;
339: <PJ>, thumbnails;
340: <PJ>, thumbnails;
341: <PJ>, thumbnails;
342: based on <E6>;
343: based on <E5>;
344: based on <E3>;
345: based on <G5>;
346: based on <S3>;
347: based on <G1>;
348: based on <F5>;
349: based on <pavAppendixA-F5>;
350: based on <pavAppendixA-F5>;
351: based on <F7>;
352: based on <A4>;
353: based on <D7>;
354: <PJ>, thumbnails, <A1>;
355: <PJ> 1040626;
356: <PJ> 1040631;
357: <PJ> 1040614;
358: <Flickr_userSteelersliu> 4893610612_4bdb000c5a_o;
359: <Flickr_userDMorency> 2232247367_fc860653dd_o;
360: <PJ> 1040764;
361: <PJ> 1040719;
362: <PJ>, thumbnails;
363: <PJ>, thumbnails;
364: <PJ>;
365: <PJ>;
366: <PJ>, thumbnails, <A2>;
367: <PJ>, thumbnails;
368: <PJ>, thumbnails;
369: <PJ>;

 18. Image References

Many tables also embed photographs:

```
Table 1: <PJ>, <E3>, <E4>;
Table 2: <PJ>, <E3>, <E4>;
Table 3: <PJ>, <E3>, <E4>;
Table 4: <PJ>, <E3>, <E4>;
Table 5: <PJ>, <E3>, <E4>;
Table 6: <PJ>, <E3>, <E4>;
Table 7: <PJ>, <E3>, <E4>;
Table 8: <PJ>, <E3>, <E6>;
Table 9: <PJ>, <E3>, <E6>;
Table 10: <PJ>, <E3>, <E6>;
Table 11: <PJ>, <E3>, <E6>;
Table 12: <PJ>, <E3>, <E6>;
Table 13: <PJ>, <E3>, <E6>;
Table 14: <PJ>, <E3>, <E6>;
Table 15: <PJ>, <E1>, <E3>;
Table 16: <PJ>, <E1>, <E3>;
Table 17: <PJ>, <E1>, <E3>;
Table 18: <PJ>, <E1>, <E3>
Table 19: <PJ>, <E1>, <E3>;
Table 20: <PJ>, thumbnails, <A1>, <A2>, <A3>, <A4>, <A5>, <A6>, <A7>;
Table 21: <PJ>, thumbnails, <A1>, <A2>, <A3>, <A4>, <A5>, <A6>, <A7>;
Table 22: <PJ>, thumbnails, <A1>, <A2>, <A3>, <A4>, <A5>, <A6>, <A7>;
Table 23: <PJ>, thumbnails, <B1>, <B2>, <B3>, <B4>, <B5>, <B6>, <B7>;
Table 24: <PJ>, thumbnails, <C1>, <C2>, <C3>, <C4>, <C5>, <C6>, <C7>;
Table 25: <PJ>, thumbnails, <D1>, <D2>, <D3>, <D4>, <D5>, <D6>, <D7>;
Table 26: <PJ>, thumbnails, <E1>, <E2>, <E3>, <E4>, <E5>, <E6>, <E7>;
Table 27: <PJ>, thumbnails, <F1>, <F2>, <F3>, <F4>, <F5>, <F6>, <F7>;
Table 28: <PJ>, thumbnails, <G1>, <G2>, <G3>, <G4>, <G5>, <G6>, <G7>;
Table 29: <PJ>, thumbnails, <H1>, <H2>, <H3>, <H4>, <H5>, <H6>, <H7>;
Table 30: <PJ>, thumbnails, <S1>, <S2>, <S3>;
Table 31: <PJ>, thumbnails, <T1>, <T2>, <T3>;
Table 32: <PJ>, thumbnails, <U1>, <U2>, <U3>;
Table 33: <PJ>, thumbnails, <V1>, <V2>, <V3>;
Table 34: <PJ>, thumbnails, <W1>, <W2>, <W3>;
Table 35: <PJ>, thumbnails, <X1>, <X2>, <X3>;
Table 36: <PJ>, thumbnails, <Y1>, <Y2>, <Y3>;
Table 37: <PJ>, thumbnails, <Z1>, <Z2>, <Z3>;
Table 38: <PJ>, thumbnails;
Table 39: <PJ>, thumbnails, <B1>, <C3>, <F2>, <H3>;
Table 40: <PJ>, thumbnails, <A3>, <E3>, <F3>, <U1>;
Table 41: <PJ>, thumbnails, <B2>, <E1>, <E2>, <G3>;
Table 42: <PJ>, thumbnails, <C1>, <C2>, <G2>;
Table 43: <PJ>;
Table 44: <PJ>;
```

 18. Image References

80 Default Photographs of the 80 World Exposition Pavilions

We singles out 80 World Exposition pavilions, which appear multiple times in various Figures and Tables. There is always one default photograph for each project. The following table cross references the sources and maps the keys like <A1>:

```
<A1>: <Expo2010ShanghaiChinaFromTheAir> 019;
<A2>: <Flickr_userMarcaurel> 5208134351_7788801c75_o;
<A3>: <ArchivesdemontrealIcaAtomOrg> VM94-EX281-027;
<A4>: <Expo2010ShanghaiChinaFromTheAir> 037;
<A5>: <Expo2010ShanghaiChinaFromTheAir> 024;
<A6>: <Flickr_userWentaoYin12> 5550288856_e2bd91d58a_o;
<A7>: <Expo2010ShanghaiChinaFromTheAir> 033;
<B1>: <PoltrackNet_byJohnPoltrack> USSRPavilion1970-20131114;
<B2>: <CollectionscanadaGcCa> e000990864;
<B3>: <PinterestArchitekturaPh> b4c2265c30e616368851ecc475585934;
<B4>: <Flickr_userChris0405> 5136795772_c9bd 7796_o;
<B5>: <Expo2010ShanghaiChinaFromTheAir> 120;
<B6>: <Flickr_userJohnClaudi> 11069025224_f6cc97a3d5_o;
<B7>: <ArchdailyCom> 1312860908-image-38;
<C1>: <Flickr_userWojtekgurak> 5417727359_865fc7ae6f_o;
<C2>: <Flickr_userFrankschacht> 4997424655_73ecd09a48_b;
<C3>: <ArchivesdemontrealIcaAtomOrg> VM94-B253-014;
<C4>: <Flickr_userFrankschacht> 4663059809_26d8f763eb_b;
<C5>: <Flickr_userWojtekgurak> 5466772900_2a9d7895b3_o;
<C6>: <Flickr_userKimon> 4691922765_26d9673878_o;
<C7>: <Flickr_userGavinbloys> 5679031723_faf51d6206_o;
<D1>: <Flickr_userMagstb67> 8218671921_930da04a04_o;
<D2>: <CollectionscanadaGcCa> e000990843;
<D3>: <Flickr_userThePieShopsCollection> 3750276283_26d3059f98_b;
<D4>: <PJ> 1040415;
<D5>: <Expo2010ShanghaiChinaFromTheAir> 046;
<D6>: <Expo2010ShanghaiChinaFromTheAir> 027;
<D7>: <Flickr_userKOota> 5798600785_f0040bc9e6_o;
<E1>: <ArchivesdemontrealIcaAtomOrg> VM94-EX264-012;
<E2>: <Flickr_userSteelersliu> 4893610612_4bdb000c5a_o;
<E3>: <Flickr_userThePieShopsCollection> 7766428922_144da4f956_b;
<E4>: <Expo2010ShanghaiChinaFromTheAir> 015;
<E5>: <Flickr_userMLouis> 1182780849_4f3eaf9d63_o;
<E6>: <ArchivesdemontrealIcaAtomOrg> VM94-EX265-127;
<E7>: <Flickr_userExpomuseum> 4781946933_842870d856_o;
<F1>: <PoltrackNet_byJohnPoltrack> FujiGroupPavilion-20131103;
<F2>: <Expo2010ShanghaiChinaFromTheAir> 001;
<F3>: <Wikipedia_byJensBludau> Expo2000Japan;
<F4>: <Panoramio__user775448-brickl> 26719555;
<F5>: <PJ> 1040420;
<F6>: <Panoramio_userPlumgarden_(54048)> 76578551;
<F7>: <AstudejaoublieBlogspotFr_byFukudaCard> japon18;
<G1>: <Flickr_userThePieShopsCollection> 5560908841_0cf4e19fa9_b;
<G2>: <Flickr_userExpomuseum> 7836263826_7724ac7827_o;
<G3>: <Wikipedia_byAxelHH> Deutscher_Pavillon_2011;
<G4>: <Flickr_userFrankschacht> 4629685266_3a1c0274ee_b;
<G5>: <Flickr_userBdutfield> 3090633791_b84504c9f9_o;
<G6>: <PJ> P1050751;
<G7>: <24621953AtIebryInfo_byTetsuo> 1323610946514l3219435_osak-ban-sen;
<H1>: <Expo2010ShanghaiChinaFromTheAir> 026;
<H2>: <Expo2010ShanghaiChinaFromTheAir> 044;
<H3>: <Flickr_userWojtekgurak> 5469176217_63aaf97127_o;
<H4>: <Expo2010ShanghaiChinaFromTheAir> 047;
<H5>: <Expo2010ShanghaiChinaFromTheAir> 167;
<H6>: <PJ> espana-1030389;
<H7>: <Panoramio__user775448-brickl> 32940691;
<S1>: <Expo2010ShanghaiChinaFromTheAir> 020a;
<S2>: <Flickr_userSteelersliu> 4893608054_420b9fc5b2_o;
<S3>: <AlamedainfoCom> expo_67_Montreal_Canada_The_Czechoslovak_Pavilion_ADEX314;
<T1>: <Panoramio_user(utf8)_(3705168)> 76721995;
<T2>: <Flickr_userKimon> 4633716458_6870e80b8b_o;
<T3>: <Panoramio_user(utf8)_(3705168)> 76721979;
<U1>: <Expo67NcfCa_byThomasNelson> z_netherlands;
<U2>: <Panoramio_user239280_(Baycrest)> 56967092;
<U3>: <Flickr_userPetespix75> 4381419661_9e6baae671_o;
<V1>: <ArchivesdemontrealIcaAtomOrg> VM94-EX265-138;
<V2>: <Flickr_userLizstless> 432849205_ad89edabfb_o;
<V3>: <ArchivesdemontrealIcaAtomOrg> VM94-B208-021;
<W1>: <Flickr_userKimon> 4633171163_a3dcc6b589_o;
<W2>: <Flickr_userExpomuseum> 4684914512_510197747a_o;
<W3>: <PJ> P1050727;
```

 18. Image References

<X1>: <Expo2010ShanghaiChinaFromTheAir> 036b;
<X2>: <ArchivesdemontrealIcaAtomOrg> VM94-B220-064;
<X3>: <Life_byCarlMydans> 06 TimeLife_image_5919616 IgGeZAB_XDFFXw;
<Y1>: <Flickr_userWojtekgurak> 5513020721_5e3d2b4dfd_o;
<Y2>: <Expo2010ShanghaiChinaFromTheAir> 042c;
<Y3>: <Panoramio_userXiemingjun3616879> 35039246;
<Z1>: <CollectionscanadaGcCa> e000990839;
<Z2>: <Flickr_userWojtekgurak> 5463400364_08360ee750_o;
<Z3>: <Life_byCarlMydans> 09 TimeLife_image_5919617 5wGq4_mbmyE1lw;

Origins of Photographs

Most photographs of pavilions have been accessed in the summer of 2014, when a specific date could not be recreated, the more general date "2014" is supplied.

<PJ> Special value: By the author Philipp Jurewicz

<24621953AtIebryInfo_byTetsuo> Tetsuo https://24621953.at.webry.info/201112/article_2.html
accessed 2014
<AlamedainfoCom> https://alamedainfo.com/
accessed 2014
<ArchdailyCom> https://www.archdaily.com/157658/ad-classics-expo-58-philips-pavilion-le-corbusier-and-iannis-xenakis/image-38
accessed April 13, 2014
<ArchivesdemontrealIcaAtomOrg> *Archives de la Ville de Montréal*
Attribution-NonCommercial-ShareAlike 2.5 Canada (CC BY-NC-SA 2.5 CA)
https://archivesdemontreal.ica-atom.org
accessed 2014
<AstudejaoublieBlogspotFr_byFukudaCard> http://astudejaoublie.blogspot.com/
accessed 2014
<BingMaps> Microsoft Corporation, "Satellite Images From Shanghai World Exposition Site",
accessed 2014-11-09, (c) 2014 Nokia, (c) 2014 DigitalGlobe, (c) Microsoft Corporation
the original screenshots are cropped for the research purpose, accessed 2014
<CollectionscanadaGcCa> Library and Archives Canada – https://collectionscanada.gc.ca/
https://www.bac-lac.gc.ca/eng
accessed 2014
<Expo2010ShanghaiChinaFromTheAir>
Book publication: Er, Dongqiang. *Expo 2010: Shanghai China from the Air*. Hong Kong: Old China Hand Press, 2010.
<Expo67NcfCa_byThomasNelson> http://expo67.ncf.ca/expo_netherlands_p1.html "Expo 67 Montreal Canada." Toronto: Thomas Nelson & Sons, 1968, accessed 2014
<Expo67NcfCa_byGilesClouatre> Giles Clouatre http://expo67.ncf.ca/expo_67_austria_p1.html
"Austrian Pavilion" accessed 2014
<Flickr_userAnnamagal> Anna Magal https://www.flickr.com/photos/annamagal/
accessed: 2014; 6201288571_73b79781b2_o
<Flickr_userBdutfield> Bill Dutfield https://www.flickr.com/photos/wdd100
accessed April 13, 2014
<Flickr_userCesarCorona> César Corona https://www.flickr.com/photos/cesar_corona
accessed April 13, 2014
<Flickr_userChris0405> Chi Shao Chen https://www.flickr.com/photos/chris0405
accessed May 18, 2014
<Flickr_userChimaybleue> chimaybleue https://www.flickr.com/photos/54061828@N07
accessed: Mai 29, 2014
<Flickr_userDMorency> David Morency https://www.flickr.com/photos/107066872@N02
accessed: 2014; 2232247367_fc860653dd_o
<Flickr_userExpomuseum> ExpoMuseum https://www.flickr.com/photos/expomuseum
accessed April 13, 2014
<Flickr_userFrankschacht> frank schacht https://www.flickr.com/photos/frankschacht
accessed May 18, 2014
<Flickr_userGavinbloys> gavin bloys https://www.flickr.com/photos/gavinbloys
accessed May 18, 2014
<Flickr_userHtglss> Jonghee Park https://www.flickr.com/photos/htglss
accessed June 13, 2014
<Flickr_userJohnClaudi> https://www.flickr.com user not recoverable,
accessed 2014; 11069025224_f6cc97a3d5_o
<Flickr_userKimon> Kimon Berlin https://www.flickr.com/photos/kimon
accessed May 18, 2014
<Flickr_userKOota> https://www.flickr.com user not recoverable,
accessed 2014; 5798600785_f0040bc9e6_o
<Flickr_userLaurentBaudoux> RB DX https://www.flickr.com/photos/residencebaudoux
accessed: 2014; 304876264_d01ed04101_o
<Flickr_userLizstless> Rick Webb https://www.flickr.com/photos/lizstless
accessed: 2014; 432849205_ad89edabfb_o
<Flickr_userMagstb67> Marc-A. G. https://www.flickr.com/photos/61779764@N00
accessed: 2014; 8218671921_930da04a04_o
<Flickr_userMarcaurel> Marc Aurel https://www.flickr.com/photos/marcaurel
accessed May 18, 2014
<Flickr_userMarconunes> Marco Nunes https://www.flickr.com/photos/marconunes
accessed: 2014; 3544119979_12bde35b9a_o

 18. Image References

<Flickr_userMeiguoxing> meiguo Xing https://www.flickr.com/photos/23665309@N02
accessed May 29, 2014

<Flickr_userMLouis> https://www.flickr.com user not recoverable
accessed 2014; 1182780849_4f3eaf9d63_o

<Flickr_userPetespix75> Henry Petermann https://www.flickr.com/people/46633980@N04/
accessed April 14, 2014

<Flickr_userPicturenarrative> picturenarrative https://www.flickr.com/photos/picturenarrative
accessed May 18, 2014

<Flickr_userSophieetfred> Sophie et Fred https://www.flickr.com/photos/47412998@N08
accessed May 18, 2014; 5193796491_83f0c58159_o

<Flickr_userSSchleicher> Simon Schleicher https://www.flickr.com/photos/80005875@N04
accessed June 13, 2014; 7334127378_525bf5cd4c_b

<Flickr_userSteelersliu> Felix Liu https://www.flickr.com/photos/liuyuhong
accessed May 18, 2014

<Flickr_userThePieShopsCollection> Cardboard America Collection
https://www.flickr.com/photos/hollywoodplace
accessed April 13, 2014

<Flickr_userWentaoYin12> Beijing1211 https://www.flickr.com/photos/7720941@N08
accessed May 18, 2014

<Flickr_userWojtekgurak> Wojtek Gurak https://www.flickr.com/photos/wojtekgurak
accessed May 18, 2014

<GoogleMaps> https://www.google.at/maps “Satellite Images From Shanghai World Exposition Site”, Google Maps, accessed 2014
the original screenshots are cropped for the research purpose

<Life_byCarlMydans> https://www.life.com/photographer/carl-mydans/
“Expo ‘70” photographer Carl Mydans 1970, LIFE (c) Time Inc.

<Life_byMichaelRougier> https://www.life.com/photographer/michael-rougier/
https://artsandculture.google.com/asset/expo-67/KAFpV-9Op0SG6g
“Expo '67” photographer Michael Rougier 1967, LIFE (c) Time Inc.

<Panoramio_user(utf8)_(3705168)> http://www.panoramio.com/ Google Inc. site discontinued 2016
accessed 2014

<Panoramio_user239280_(Baycrest)> http://www.panoramio.com/ Google Inc. site discontinued 2016
accessed 2014

<Panoramio__user775448-brickl> http://www.panoramio.com/ Google Inc. site discontinued 2016
accessed 2014

<Panoramio_userPlumgarden_(54048)> http://www.panoramio.com/ Google Inc. site discontinued2016
accessed 2014

<Panoramio_userXiemingjun3616879> http://www.panoramio.com/ Google Inc. site discontinued 2016
accessed 2014

<PinterestArchitekturaPh> https://www.pinterest.com/
accessed 2014

<PoltrackNet_byJohnPoltrack> https://poltrack.net/ by John M Poltrack accessed 2014,
photos are also available on the photographers Flickr account
https://www.flickr.com/photos/poltracknet/32331905378/in/album-72157702448582074/
https://www.flickr.com/photos/poltracknet/46153314452/in/album-72157702448582074/

<SDA> Content from the “Structures Design Aid Database” headed by Vinzenz Sedlak.
Supporting academic publications: (Sedlak, 1996), (Sedlak, 1997)

<StatesOfArchitectures_byNicLehoux>
Book publication: Riera Ojeda, Oscar, Rodolphe El-Khoury, and Andrew Payne. *States of Architecture in the Twenty-First Century: New Directions from the Shanghai World Expo*, 2011.

<TokyoskyTo> http://tokyosky.sub.jp/tokyosky_webmasters_blog/assets_c/2012/01/EXPO70-142.html
accessed 2014

<UncubeMagazine_byShunkKender> photographer Shunk-Kender,(c) Roy Lichtenstein Foundation, courtesy Experiments in Art & Technology)

<wikipedia-userMarcusrg> "Das Museum für zeitgenössische Kunst in Niterói”, Marcusrg, 2006,
CC BY 2.0
https://de.wikipedia.org/wiki/Museu_de_Arte_Contempor%C3%A2nea_de_Niter%C3%B3i#/media/Datei:Museu_de_Arte_Contempor%C3%A2nea_de_Niter%C3%B3i.jpg

<Wikipedia-userWaitingxu> ‘Tree structure of "Colourless green ideas sleep furiously"’,
Waitingxu, 16 November 2014
CC-BY-SA-4.0
https://commons.wikimedia.org/wiki/File:Colorless_green_idea.png

<Wikipedia-userUlomekFotoDe> “Das Horizont-Observatorium”, Ulomek-foto-de, 21. Januar 2014,
CC BY-SA 3.0; accessed 2014
https://de.wikipedia.org/wiki/Halde_Hoheward#/media/Datei:Hoheward_Horizont_Observatorium_2.jpg

<Wikipedia_byJensBludau> “Japanischer Pavillon von Shigeru Ban”, Jens Bludau, Oktober 2000,
CC BY-SA 3.0; accessed 2014
https://de.wikipedia.org/wiki/Expo_2000#/media/Datei:Expo2000Japan.jpg

<Wikipedia_byAxelHH> “Deutscher Pavillon der Expo 2000”, Axel Hindemith, Mai 2011,
CC BY-SA 3.0; accessed 2014
https://de.wikipedia.org/wiki/Datei:Expo_2000_Deutscher_Pavillon_2011.jpg

19. Appendix Overview

19.1. Appendix A - World Exposition Pavilions with Shape Classification

This section gives an impression of Appendix A, part of the hardback printed Appendix. It is also available in the supplemented media (CD-ROM / SD-Card / Download).

jurewicz--building-shape-classification--z--appendix-a.pdf

This Appendix documents the classification of all 80 World Exposition pavilions used in the empirical part of this research. The Appendix unites two tasks:

- It shows up to nine photographs of a pavilion. These are exactly the same photographs that have been used in the data gathering described in Appendix C (19.3) and Appendix D (19.4).
- It depicts the Syntax Tree and Periphrase(s) of the pavilions. Due to the limitations of the print pages, many technical names like curvatureConvexConvex are clipped. Though the sketches are exactly the same like the exhaustive enumerations in "7.3 Periphrase Classification Sets" and "8.2 Syntax Tree Classification Sets".
  The visual notation is explained in the main document in chapter "8.3.1 Syntax Tree of the Russia Pavilion"

Some pavilions require a single page, some two or three pages:

- The pavilions that contain a single Periphrase usually fit on a single page. An example is shown in Figure 362.
- The pavilions that have a Syntax Tree, require two or threeprint pages. The first page shows the photographs, while the following pages contain the Syntax Tree at the top and the Periphrases below. An example of the second page is shown in Figure 363.

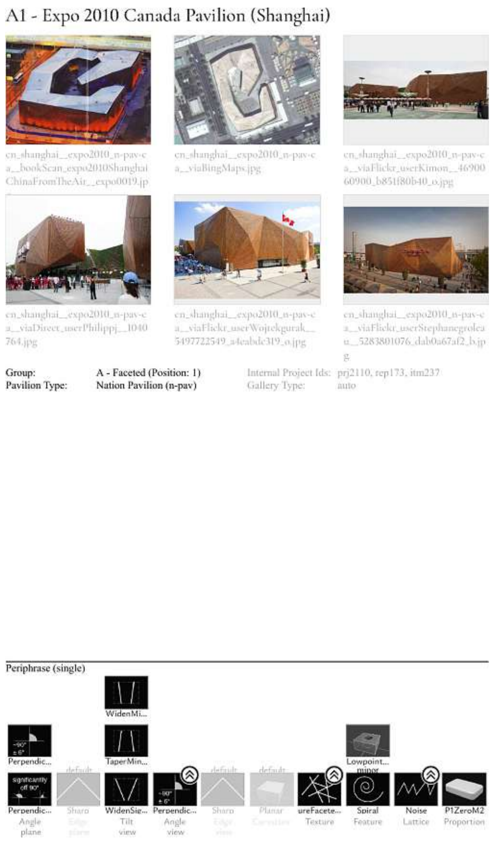


Figure 362: 1st impression of an example page of the Appendix A PDF-Document.

Pavilion that fits on a single print page

Top part: All photographs used in the empirical parts.

Bottom part: compact visualisation of the single Periphrase of the A1 pavilion

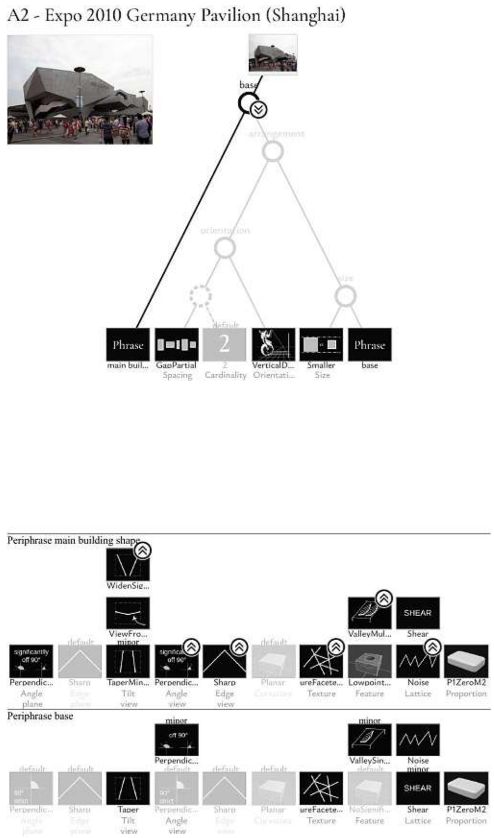


Figure 363: 2nd impression of an example page of the Appendix A PDF-Document.

Second page of a pavilion that requires 2 pages

Top part: visualisation of the Building Shape Syntax Tree of the pavilion

Bottom part: stack of all Periphrases separated by a horizontal row of the A2 pavilion

19.2. Appendix B – Weak References

This section gives an impression of Appendix B, part of the hardback printed Appendix. It is also available in the supplemented media (CD-ROM / SD-Card / Download).

jurewicz--building-shape-classification--z--appendix-b.pdf

This Appendix documents all *Named Relationships* that we discuss in “9.3 Weak References”. For convenience we repeat the used mapping between semantic and numeric values. The Appendix uses the *strength* rather then the inverted *penalty* values:

- hasVeryWeakLink 90% penalty → 10% strength
- hasWeakLink 75% penalty → 25% strength
- hasNormalLink 50% penalty → 50% strength
- hasStrongLink 25% penalty → 75% strength
- hasVeryStrongLink 10% penalty → 90% strength
- direct match no penalty → 100% strength

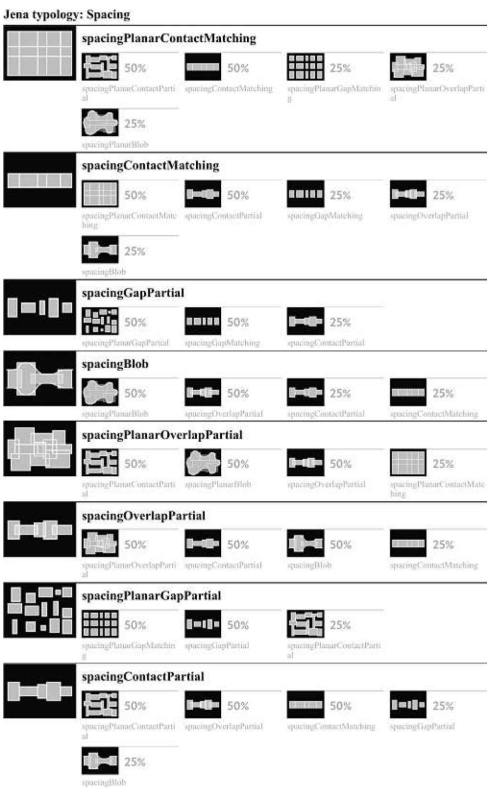


Figure 364: Impression of an example page of the Appendix B PDF-Document. As an example the fist page of the Spacing classification set.

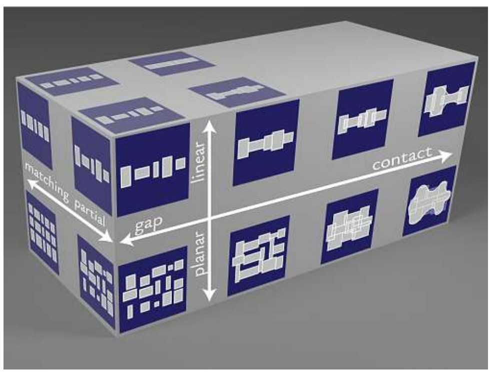


Figure 365: Visualisation of the Spacing classification set projected onto a three dimensional cube.

19.3. Appendix C - Empirical Data Per Project

This section gives an impression of Appendix C, part of the hardback printed Appendix. It is also available in the supplemented media (CD-ROM / SD-Card / Download).

jurewicz--building-shape-classification--z--appendix-c.pdf

This Appendix documents all empirical data collected during the empirical data gathering sessions as discussed in "11 Empirical Data Gathering". The only data used to verify the calculated data is the first of the nine columns. It is printed in bold and has a two digits precision; e.g. 4.33 (see Figure 367).

Still this Appendix documents the additional data as well. It divides the participants into the groups: "People with a background in architecture or civil engineering"and "lay participants" with no such educational or professional backgrounds. Most of the participants were university students of TU Wien or Universität Wien.

	participant background	encounter plate	colour
Column 1:	all participants	1st time	yellow
Column 2:	architecture background	1st time	cyan
Column 3:	lay background	1st time	pink
Column 4:	all participants	2nd time	yellow
Column 5:	architecture background	2nd time	cyan
Column 6:	lay background	2nd time	pink
Column 7:	all participants	both times	yellow
Column 8:	architecture background	both times	cyan
Column 9:	lay background	both times	pink

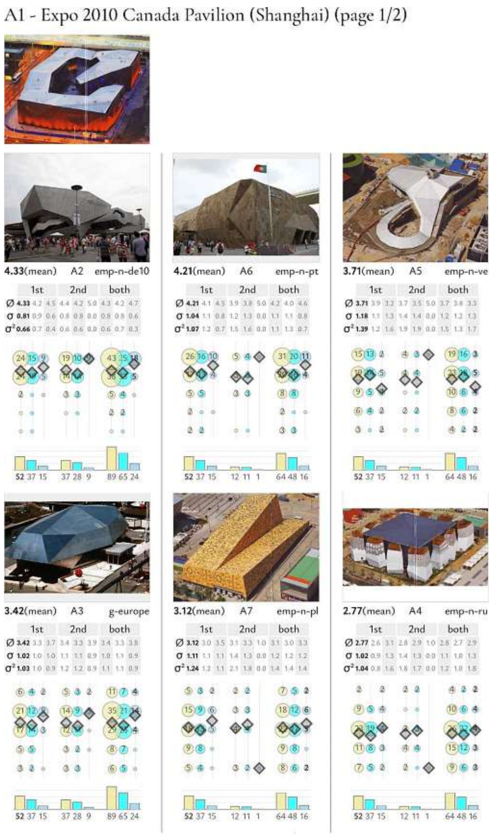


Figure 366: Impression of an example page of the Appendix C PDF-Document.

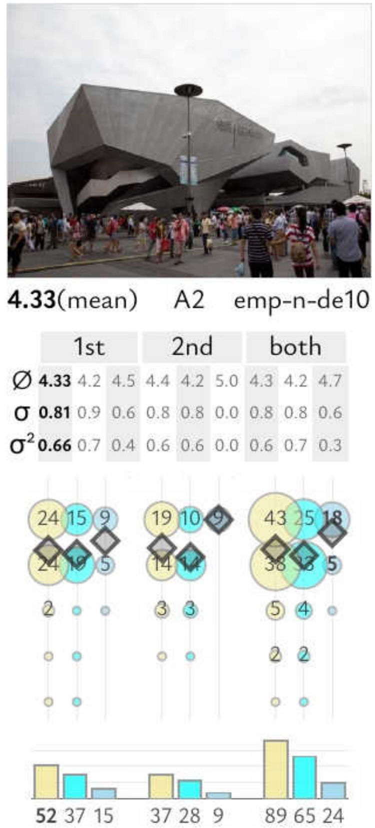


Figure 367: Close up of the chart from Appendix C PDF-Document.

The rows as depicted in Figure 367:

Table row 1	Mean value
Table row 2	Standard deviation
Table row 3	Variance

Bubble chart Ratings in the vertical slots 5, 4, 3, 2, and 1.
A small circle without a number represents the value 1.

Diamond Mean value

Bar chart Quantity of valid ratings.
When this number in the first column is smaller then 52, then some data have been removed in a clean up phase.
E.g. the participants pressed “Pause”. See chapter “11.2.9 Irregularities”

The data collected during the data gathering exceed the visualised information. Additional data points include:

- Timestamps of many user interface interactions. It would be possible to reason about the duration of the glimpses on photographs. Also re-arrangement of the ratings by the users are documented this way.
- A second type of rating as described in “11.2.8 Summary Part”

19.4. Appendix D - Data Gathering Screens

This section gives an impression of Appendix D, part of the hardback printed Appendix. It is also available in the supplemented media (CD-ROM / SD-Card / Download).

jurewicz--building-shape-classification--z--appendix-d.pdf

This Appendix documents screenshots from the web application that was used to gather the empirical data during the data gathering sessions. Six Android tablets displayed HTML pages that have been enhanced with the JavaScript programming language and were served from the authors notebook. The notebook collected all data.

Each stateful page is called *Screen/Plate* and is identified by a identification number like "A1ä". The German and French letters at the end are used as a technical convenience. Only the plates that provide data which is used in the verification of the proposed system are depicted.

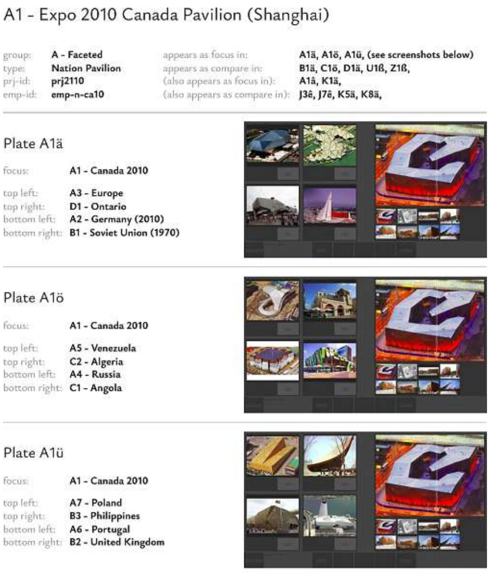


Figure 368: Impression of an example page of the Appendix D PDF-Document.

Figure 369: Tablet devices used in the empirical data gathering sessions.

19.5. Appendix E - Software Implementation

Appendix E, part of the hardback printed Appendix. It is also available in the supplemented media (CD-ROM / SD-Card / Download).

jurewicz--building-shape-classification--z--appendix-e.pdf

Appendix A

World Exposition Pavilions with Shape Classification

part of doctoral thesis

Building Shape Classification

Philipp Jurewicz 2023

Note about image references:

This appendix is part of the doctoral thesis “Building Shape Classification” at TU Wien. It contains structural data as well as photographs of World Exposition pavilions. The image references use markers in a notiontion like: <**example**>. At the end of this appendix the notation is associated with the photograph origins. Please also see the chapter “18. Image References” in the main document to understand the methodology.

A1 - Expo 2010 Canada Pavilion (Shanghai)

1. <Expo2010ShanghaiChinaFromTheAir> expo0019

2. <BingMaps>

3. <Flickr_userKimon> 4690060900_b851f80b40_o

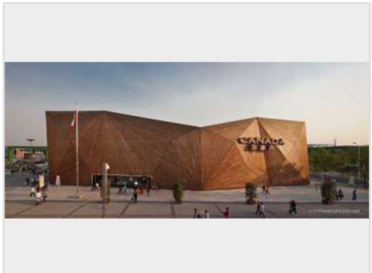
4. <PJ> 1040764

5. <Flickr_userWojtekgurak> 5497722549_a4eabdc319_o

6. <Flickr_userStephanegroleau> 5283801076_dab0a67af2_b

7. <Flickr_userFrankschacht> 4677405217_ce94c6da95_b

8. <Flickr_userStephanegroleau> 5283204829_3c68f48238_b

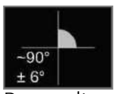


9. <Flickr_userStephanegroleau> 5283801010_b4d08b1f32_b

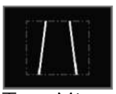
Group:	A - Faceted (Position: 1)	Year, City:	2010 Shanghai
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	ca
Empirical Id:	emp-n-ca10	Brief:	Canada (2010)
Internal Ids:	prj2110, rep173, itm237	Full:	Canada Pavilion
Tags:	expo2010/n-pav-ca/nn-canada	Qualified:	(see headline)

Periphrase (single)

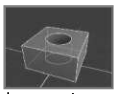
WidenMi...



Perpendic...



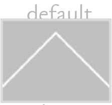
TaperMinor



Lowpoint... minor

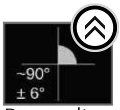
Perpendic... Angle plane

default



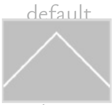
Sharp Edge plane

WidenSig... Tilt view



Perpendic... Angle view

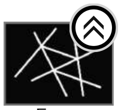
default



Sharp Edge view

default

Planar Curvature



ureFacete... Texture

Spiral Feature

Noise Lattice

P1ZeroM2 Proportion

This page intentionally left blank in print layout

A2 - Expo 2010 Germany Pavilion (Shanghai)

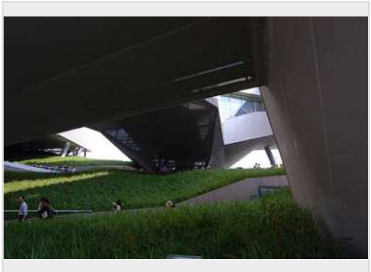
1. <Flickr_userMarcaurel> 5208134351_7788801c75_o

2. <Flickr_userKimon> 4686473229_3b0cd69e56_o

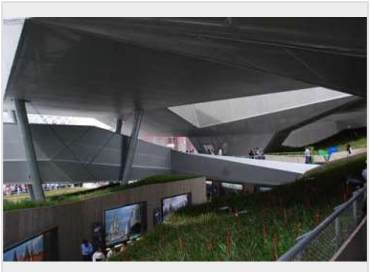
3. <Flickr_userChris0405> 5136934550_ce28eeddbb_o

4. <Flickr_userFrankschacht> 4578824650_74616ecf04_b

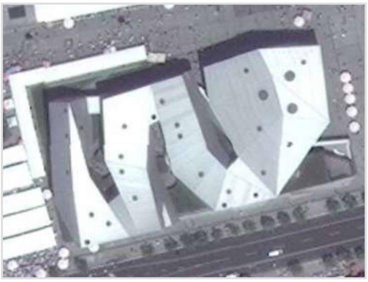
5. <Flickr_userSteelersliu> 4893028885_570a394287_o



6. <Flickr_userKommandokraus> 4647462793_82bacda330_o



7. <Flickr_userFrankschacht> 4585734127_f66cecabb7_b

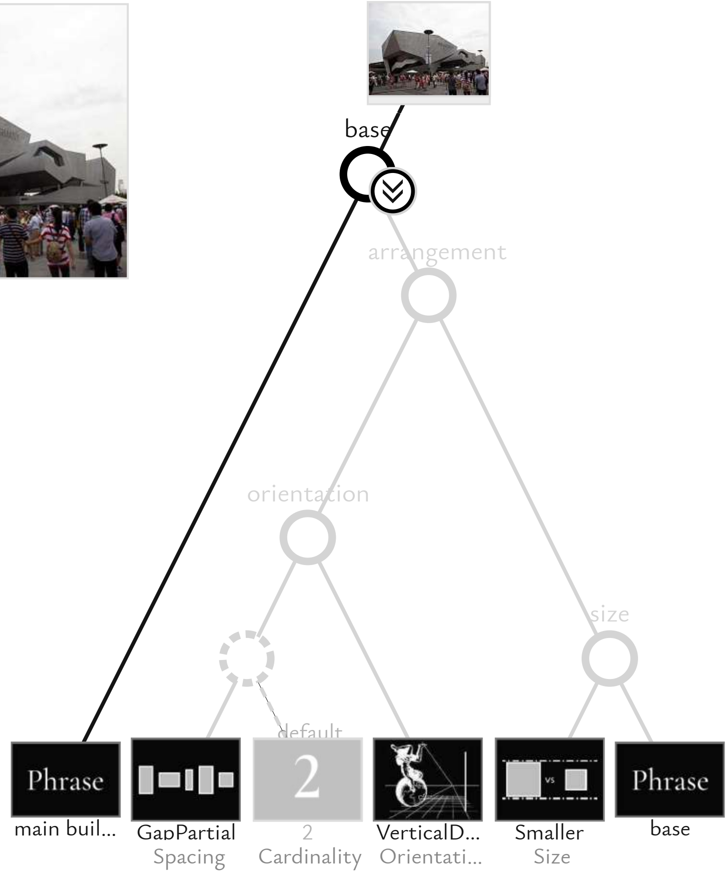


8. <BingMaps>

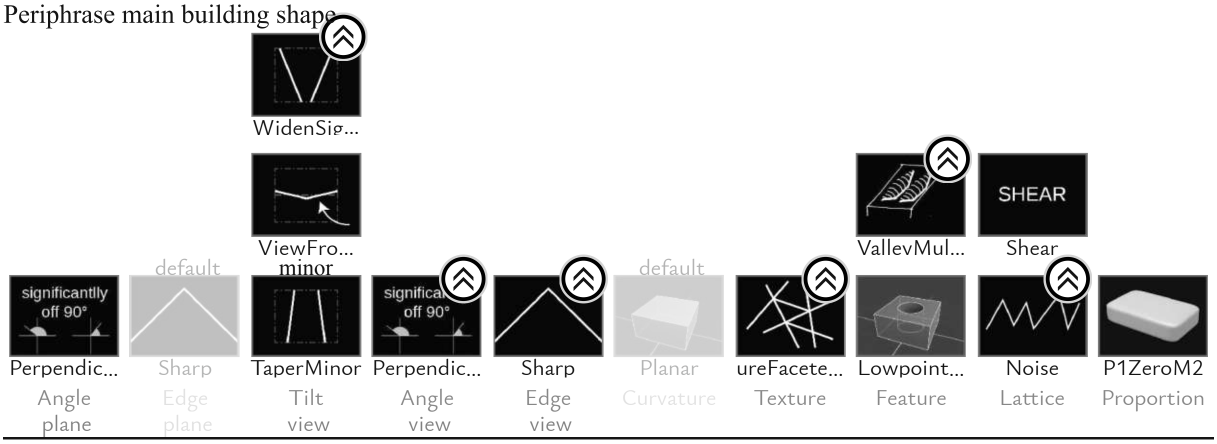
9. <Expo2010ShanghaiChinaFromTheAir> expo0030

Group:	A - Faceted (Position: 2)	Year, City:	2010 Shanghai
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	de10
Empirical Id:	emp-n-de10	Brief:	Germany (2010)
Internal Ids:	prj2116, rep174, itm214	Full:	Germany Pavilion (2010)
Tags:	expo2010/n-pav-de/nn-germany	Qualified:	(see headline)

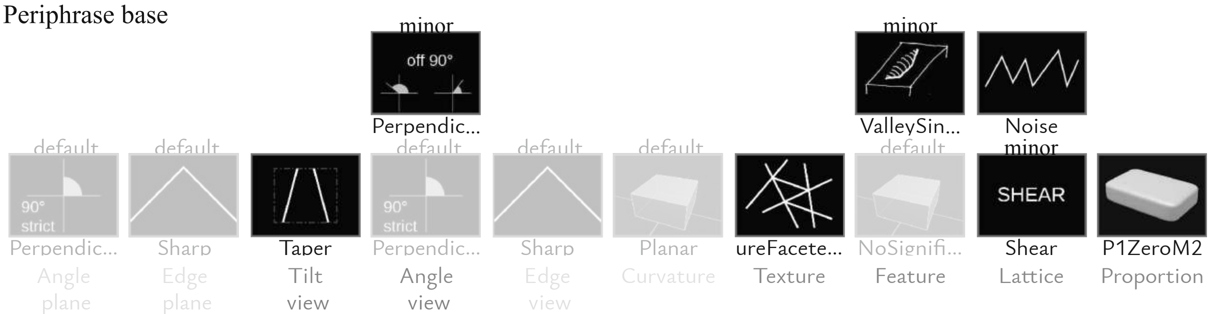
A2 - Expo 2010 Germany Pavilion (Shanghai)



Periphrase main building shape



Periphrase base



A3 - Expo 1967 Europe Pavilion (Montreal)


1. <ArchivesdemontreallcaAtomOrg> VM94-EX281-027


2. <ArchivesdemontreallcaAtomOrg> VM94-B240-014

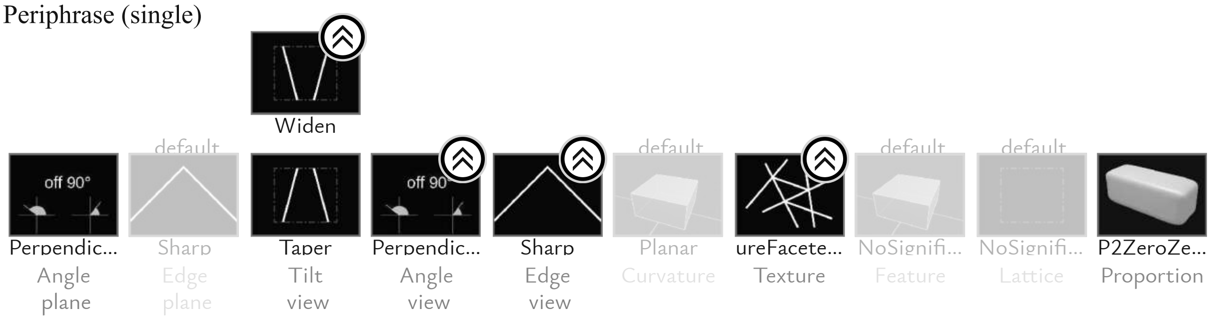

3. <Flickr_userMagstb67> 13333167834_88f82a646b_o


4. <ArchivesdemontreallcaAtomOrg> VM94-EX266-238


5. <Flickr_userErezUploadedByMagstb67> 2718334696_fb4335085f_o

Group:	A - Faceted (Position: 3)	Year, City:	1967 Montreal
Pavilion Type:	Group Pavilion (g-pav)	Shortest:	euro
Empirical Id:	emp-g-europe	Brief:	Europe
Internal Ids:	prj2513, rep175, itm209	Full:	Europe Pavilion
Tags:	expo1967/g-pav/gn-europe	Qualified:	(see headline)

Periphrase (single)



This page intentionally left blank in print layout

A4 - Expo 2010 Russia Pavilion (Shanghai)

1. <Expo2010ShanghaiChinaFromTheAir> expo0037

2. <BingMaps>

3. <Flickr_userSophieetfred> 5193796491_83f0c58159_o

4. <Flickr_userExpomuseum> 4790090062_7ff92ee854_o

5. <Flickr_userWojtekgurak> 5489885993_b657b7cc24_o

6. <PJ> 104077n-pav-ru3

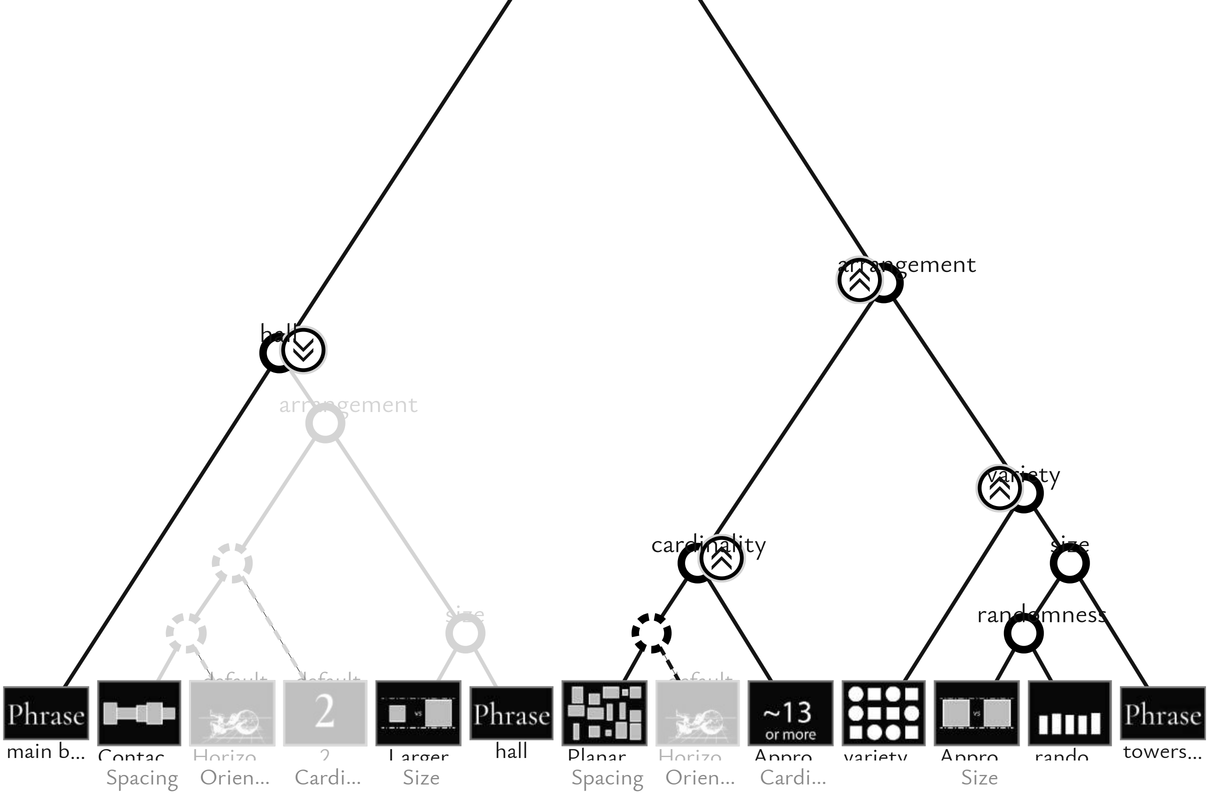
7. <Flickr_userWojtekgurak> 5489885883_173e8e7276_o

8. <PJ> 1040138

9. <PJ> 1040757

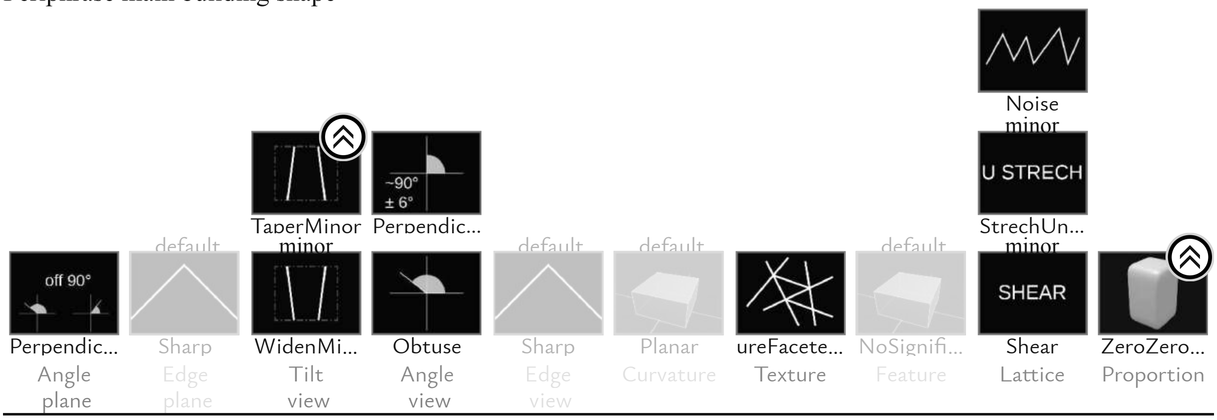
Group:	A - Faceted (Position: 4)	Year, City:	2010 Shanghai
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	ru
Empirical Id:	emp-n-ru	Brief:	Russia
Internal Ids:	prj2163, rep176, itm249	Full:	Russia Pavilion
Tags:	expo2010/n-pav-ru/nn-russia	Qualified:	(see headline)

A4 - Expo 2010 Russia Pavilion (Shanghai)

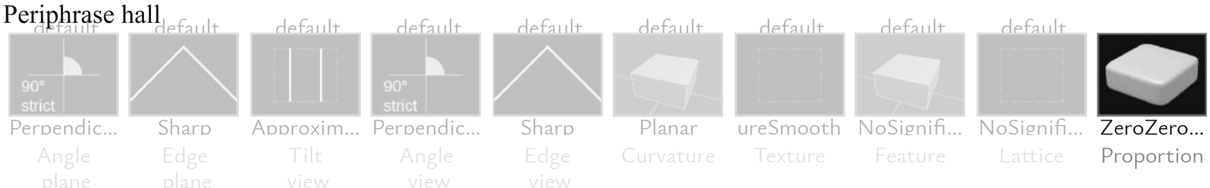


A4 - Expo 2010 Russia Pavilion (Shanghai)

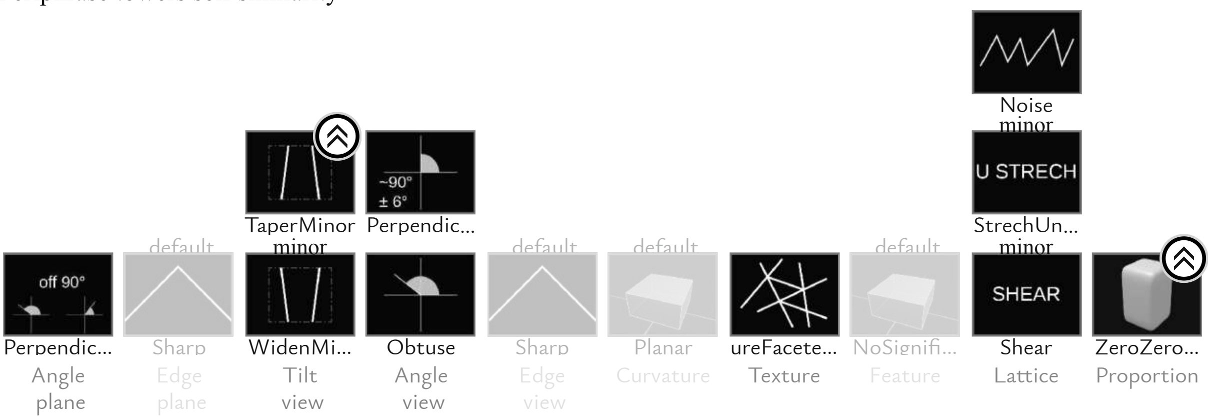
Periphrase main building shape



Periphrase hall



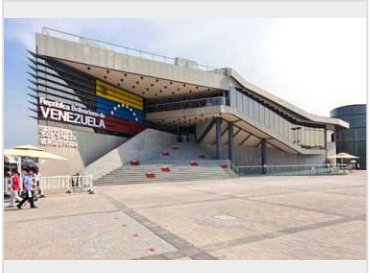
Periphrase towers self similarity



This page intentionally left blank in print layout

A5 - Expo 2010 Venezuela Pavilion (Shanghai)

1. <Expo2010ShanghaiChinaFromTheAir> expo0024



2. <Flickr_userWojtekgurak> 5448985315_ba252ffebd_o

3. <Panoramio_user604433_(utf8)> 37393322

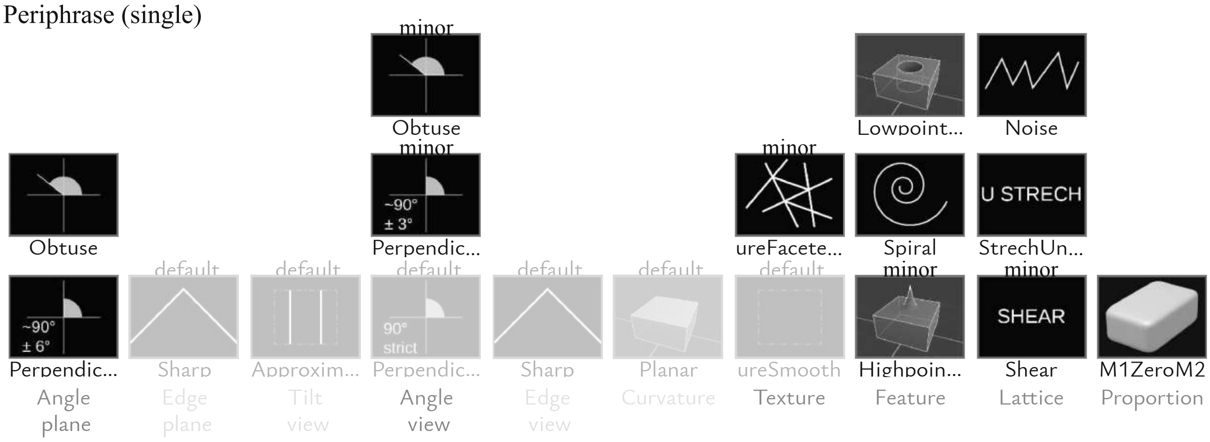
4. <BingMaps>

5. <Expo2010ShanghaiChinaFromTheAir> 165

6. <Flickr_userWojtekgurak> 5449593450_53dc5f7cc2_o

Group:	A - Faceted (Position: 5)	Year, City:	2010 Shanghai
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	ve
Empirical Id:	emp-n-ve	Brief:	Venezuela
Internal Ids:	prj2178, rep177, itm243	Full:	Venezuela Pavilion
Tags:	expo2010/n-pav-ve/nn-venezuela	Qualified:	(see headline)

Periphrase (single)



A6 - Expo 2010 Portugal Pavilion (Shanghai)


1. <Flickr_userWentaoYin12> 5550288856_e2bd91d58a_o


2. <Flickr_userBolorocco> 5197293515_44ff88722e_o

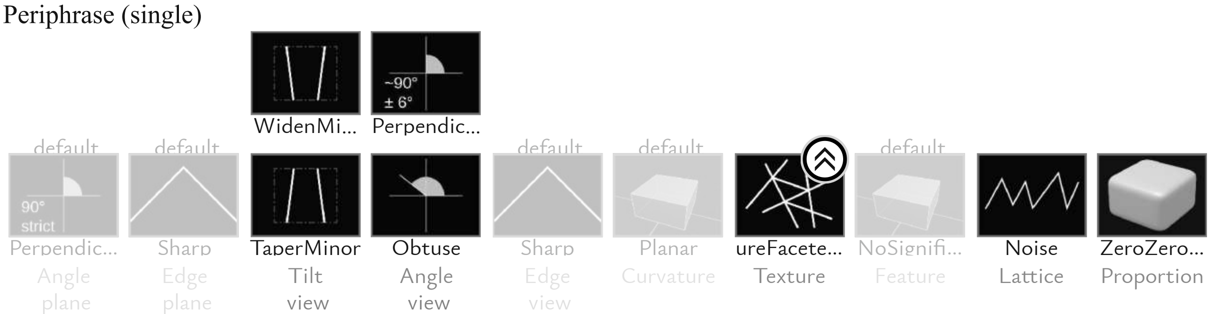

3. <Flickr_userExpomuseum> 4714925856_f67bdc718b_o


4. <BingMaps>


5. <PJ> 1040076

Group:	A - Faceted (Position: 6)	Year, City:	2010 Shanghai
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	pt
Empirical Id:	emp-n-pt	Brief:	Portugal
Internal Ids:	prj2159, rep178, itm217	Full:	Portugal Pavilion
Tags:	expo2010/n-pav-pt/nn-portugal	Qualified:	(see headline)

Periphrase (single)



A7 - Expo 2010 Poland Pavilion (Shanghai)

1. <Expo2010ShanghaiChinaFromTheAir> expo0033

2. <BingMaps>

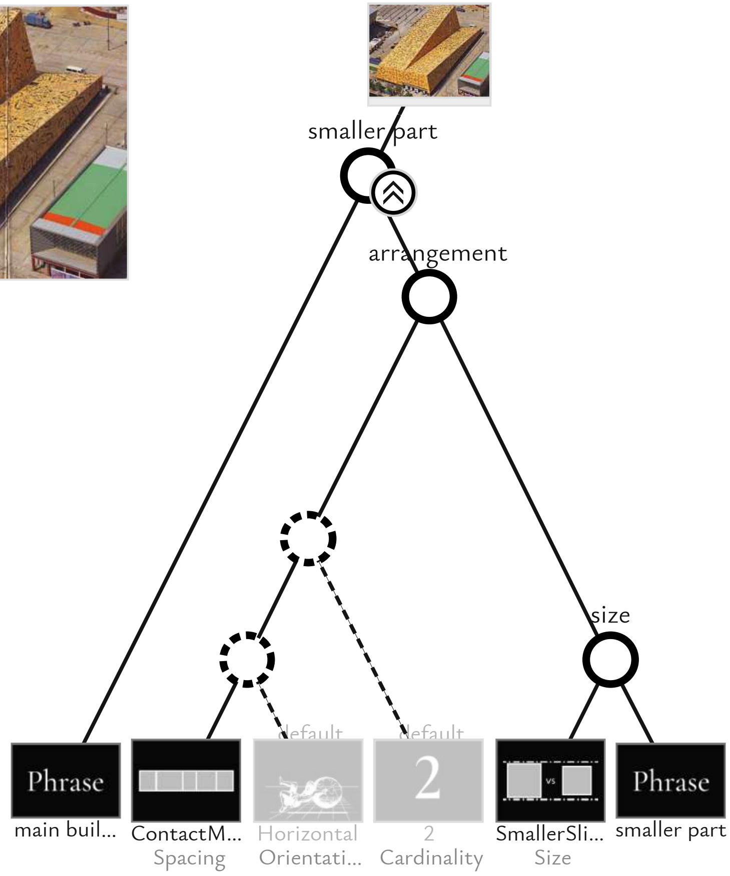
3. <Flickr_userWentaoYin12> 5237613405_3f4f29c0c8_o

4. <Flickr_userKhoavo> 4564983745_36f235aa22_o

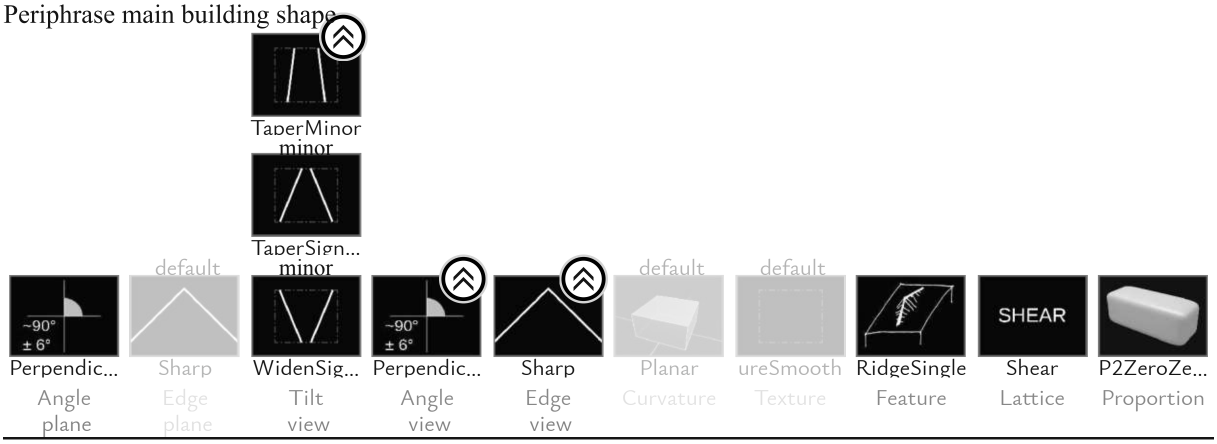
5. <Flickr_userWentaoYin12> 5238250564_fe0b67293d_o

Group:	A - Faceted (Position: 7)	Year, City:	2010 Shanghai
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	pl
Empirical Id:	emp-n-pl	Brief:	Poland
Internal Ids:	prj2158, rep198, itm238	Full:	Poland Pavilion
Tags:	expo2010/n-pav-pl/nn-poland	Qualified:	(see headline)

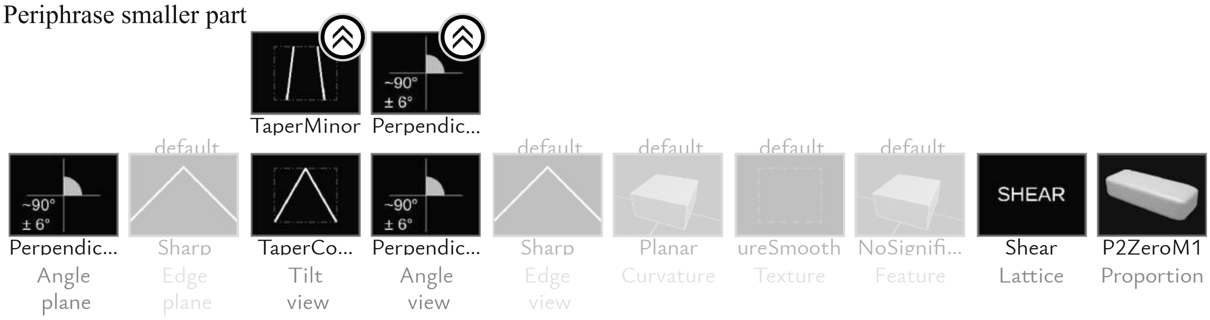
A7 - Expo 2010 Poland Pavilion (Shanghai)



Periphrase main building shape



Periphrase smaller part



B1 - Expo 1970 Soviet Union Pavilion (Osaka)

1. <PoltrackNet_byJohnPoltrack> USSRPavilion1970-20131114

2. <Flickr_userNyclondonguy> 8012564669_e345f2af42_k

3. <AstudejaoublieBlogspotFr_byFukudaCard> japon9

4. <Flickr_userAlanpPhoto> 4170443209_85d2b44441_z

5. <TokyoskyTo> EXPO70

6. <AssociatedPress> 6_13_308_img3235A

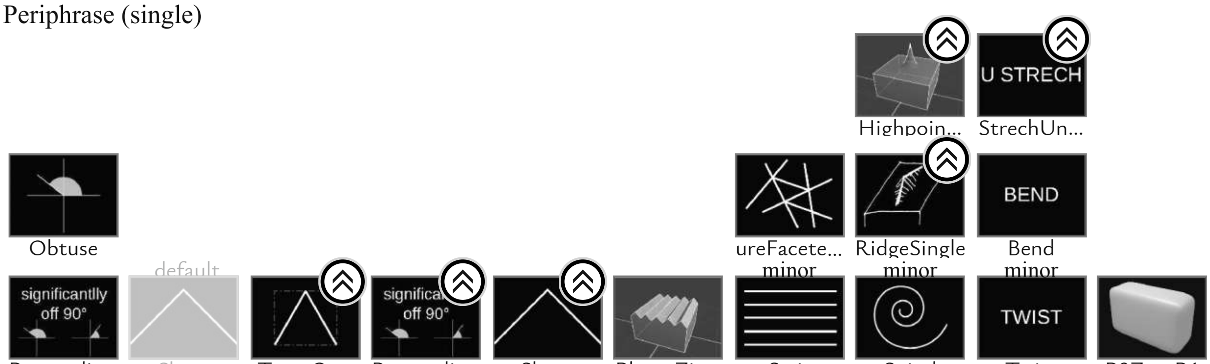
7. <Magnum_byFerdinandoScianna> PAR327605

8. <Magnum_byFerdinandoScianna> PAR327601

9. <Magnum_byFerdinandoScianna> PAR327606

Group:	B - Spike (Position: 1)	Year, City:	1970 Osaka
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	su70
Empirical Id:	emp-n-su70	Brief:	Soviet Union (1970)
Internal Ids:	prj3134, rep180, itm233	Full:	Soviet Union Pavilion (1970)
Tags:	expo1970/n-pav-su	Qualified:	(see headline)

Periphrase (single)



Highpoin... StrechUn...

Obtuse

ureFacete... minor RidgeSingle minor Bend minor

default

Perpendic... Angle plane

Sharp Edge plane

TaperCo... Tilt view

Perpendic... Angle view

Sharp Edge view

PlanarZig... Curvature

ureStripe... Texture

Spiral Feature

Twist Lattice

P2ZeroP1 Proportion

This page intentionally left blank in print layout

B2 - Expo 1967 United Kingdom Pavilion (Montreal)


1. <CollectionscanadaGcCa> e000990864


2. <Flickr_userMagstb67> 2533271246_8bfbc76404_o


3. <CollectionscanadaGcCa> e000990859


4. <ArchivesdemontrealIcaAtomOrg> VM94-EX258-003


5. <ArchivesdemontrealIcaAtomOrg> VM94-B253-012


6. <Flickr_userErezUploadedByMagstb67> 2718345474_e13e521208_o

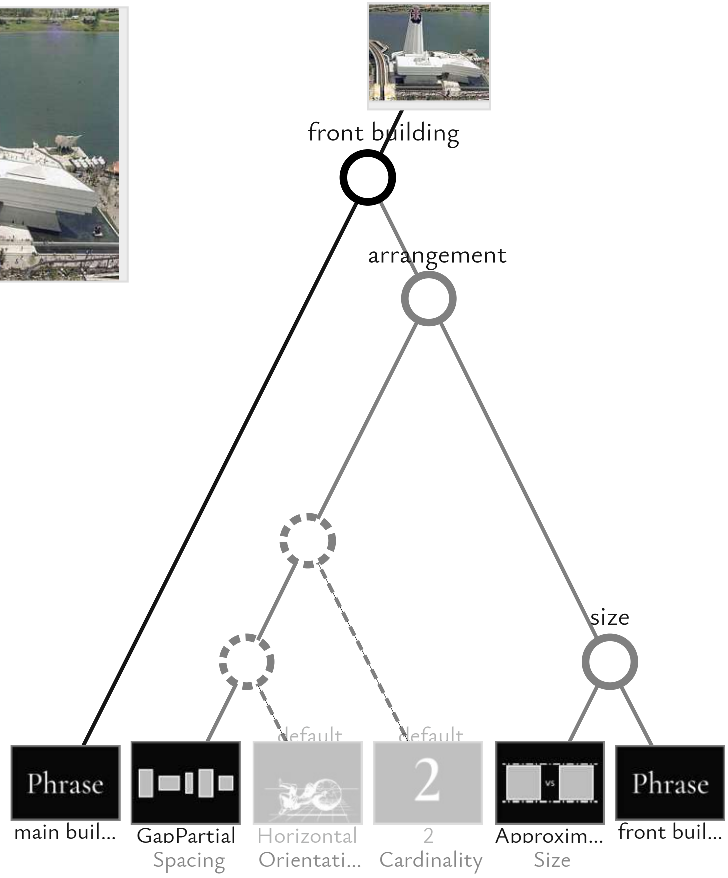

7. <ArchivesdemontrealIcaAtomOrg> VM94-EX136-573


8. <ArchivesdemontrealIcaAtomOrg> VM94-B208-041

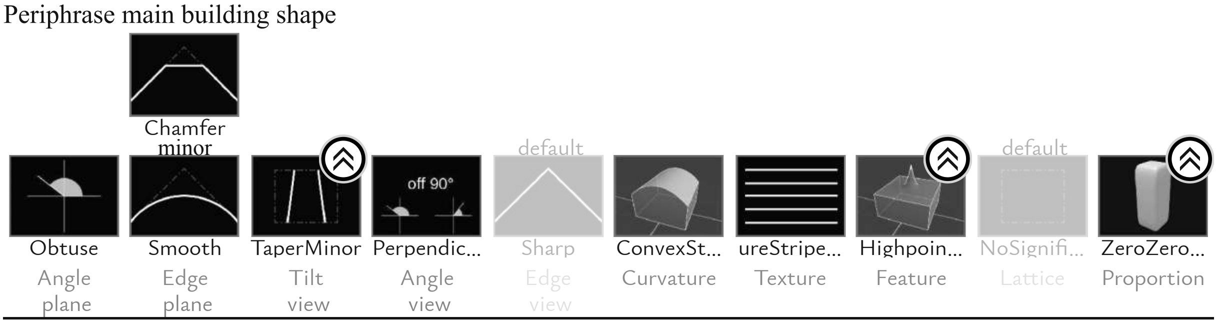

9. <GbphotodidacticalCa> Photo-Expo-67-21-Great-Britain-Pavilion

Group:	B - Spike (Position: 2)	Year, City:	1967 Montreal
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	uk
Empirical Id:	emp-n-uk	Brief:	United Kingdom
Internal Ids:	prj2432, rep181, itm256	Full:	United Kingdom Pavilion
Tags:	expo1967/n-pav-uk/nn-unitedKingdom	Qualified:	(see headline)

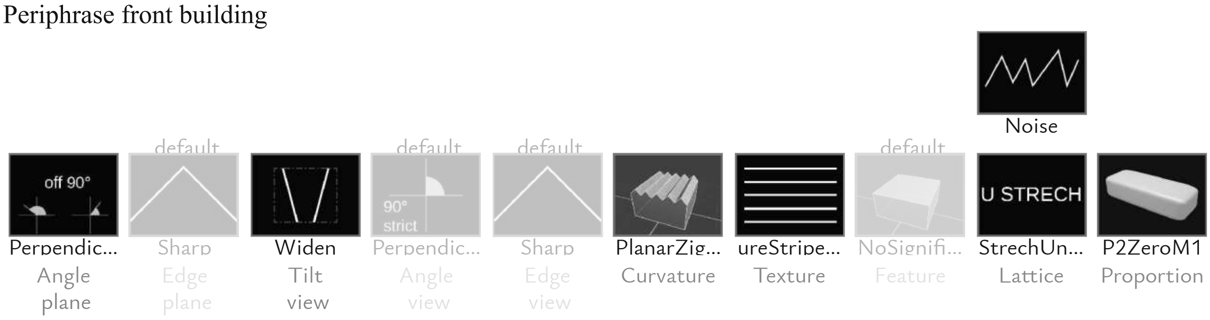
B2 - Expo 1967 United Kingdom Pavilion (Montreal)



Periphrase main building shape



Periphrase front building

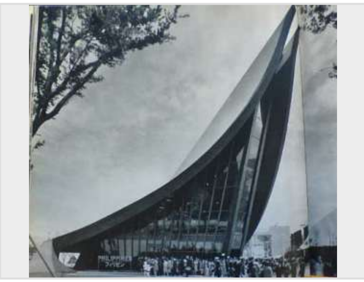


B3 - Expo 1970 Philippines Pavilion (Osaka)

1. <PinterestArchitekturaPh> b4c2265c30e616368851ecc47 5585934

2. <YouTube_userTyokutoku> 5yVvBW4p7z8_1

3. <OdasanS48XreaCom> 217

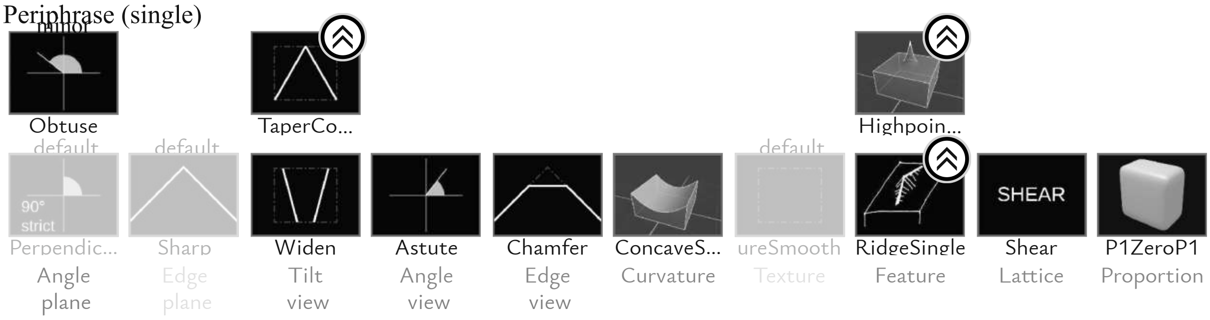


4. <Skyscrapercity_byflymorde cai> dsc01235

5. <Flickr_userLizstless> 43284 9799_3c0aa3d216_o

Group:	B - Spike (Position: 3)	Year, City:	1970 Osaka
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	ph
Empirical Id:	emp-n-ph	Brief:	Philippines
Internal Ids:	prj3131, rep182, itm199	Full:	Philippines Pavilion
Tags:	expo1970/n-pav-ph	Qualified:	(see headline)

Periphrase (single)



This page intentionally left blank in print layout

B4 - Expo 2010 Malaysia Pavilion (Shanghai)

1. <Flickr_userChris0405> 5136795772_c9bdff7796_o

2. <Flickr_userFrankschacht> 4608114923_124d907c5c_b

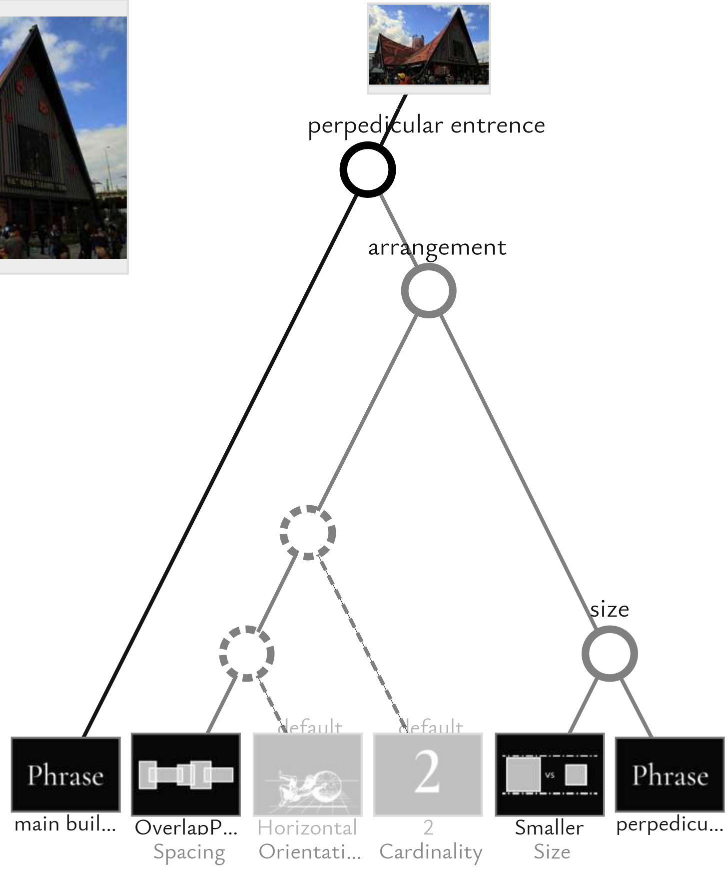
3. <Flickr_userExpomuseum> 4794417384_855414e21d_o

4. <Expo2010ShanghaiChinaFromTheAir> expo0016

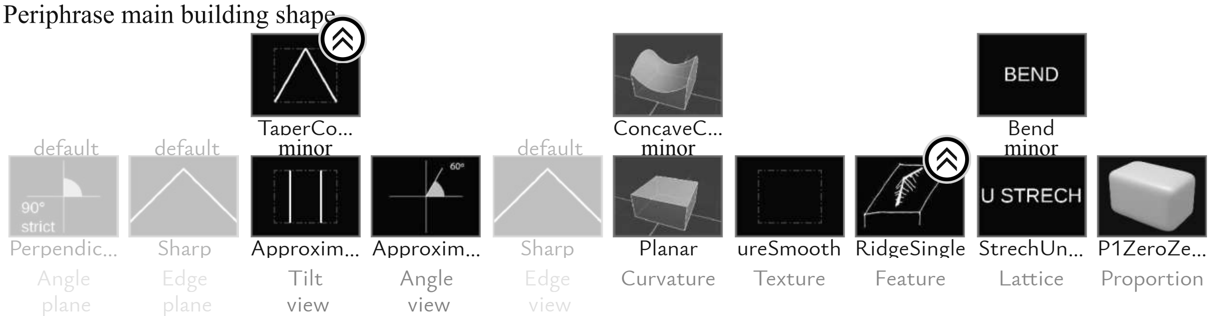
5. <GoogleMaps>

Group:	B - Spike (Position: 4)	Year, City:	2010 Shanghai
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	my
Empirical Id:	emp-n-my	Brief:	Malaysia
Internal Ids:	prj2148, rep183, itm252	Full:	Malaysia Pavilion
Tags:	expo2010/n-pav-my/nn-malaysia	Qualified:	(see headline)

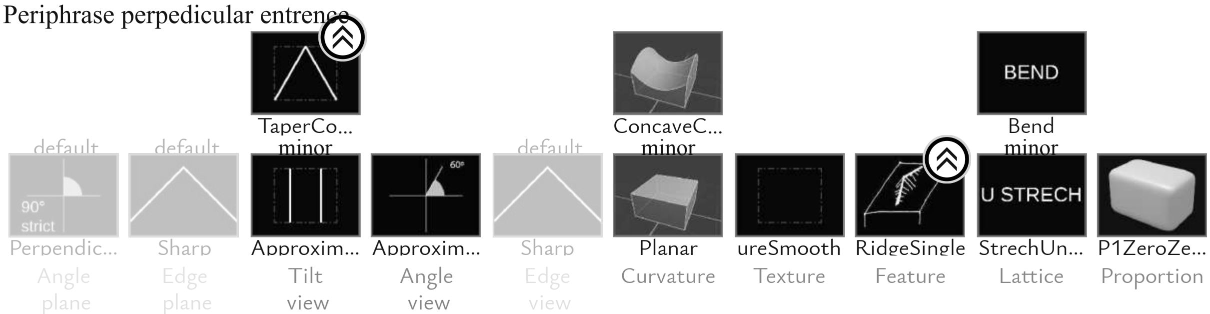
B4 - Expo 2010 Malaysia Pavilion (Shanghai)



Periphrase main building shape

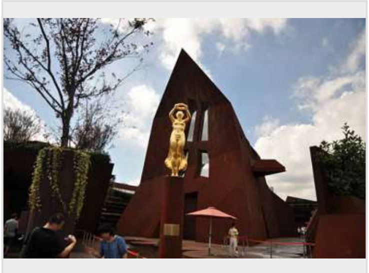


Periphrase perpedicular entrence



B5 - Expo 2010 Luxembourg Pavilion (Shanghai)

1. <Expo2010ShanghaiChinaFromTheAir> 120



2. <Flickr_userGenjiri> 5024996452_8ac42c98cd_b

3. <Flickr_userKimon> 4686479001_1aa9b68057_o

4. <Flickr_userExpomuseum> 4794073272_99d635b35c_o

5. <PJ> 1040750

6. <PJ> 1040754

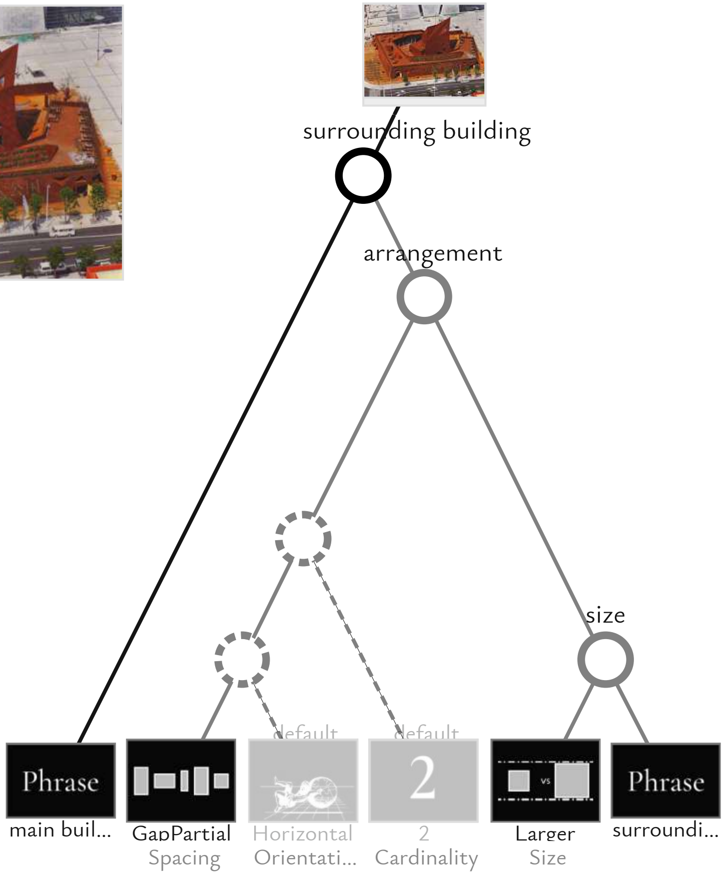
7. <GoogleMaps>

8. <StatesOfArchitectures_by NicLehoux> 1

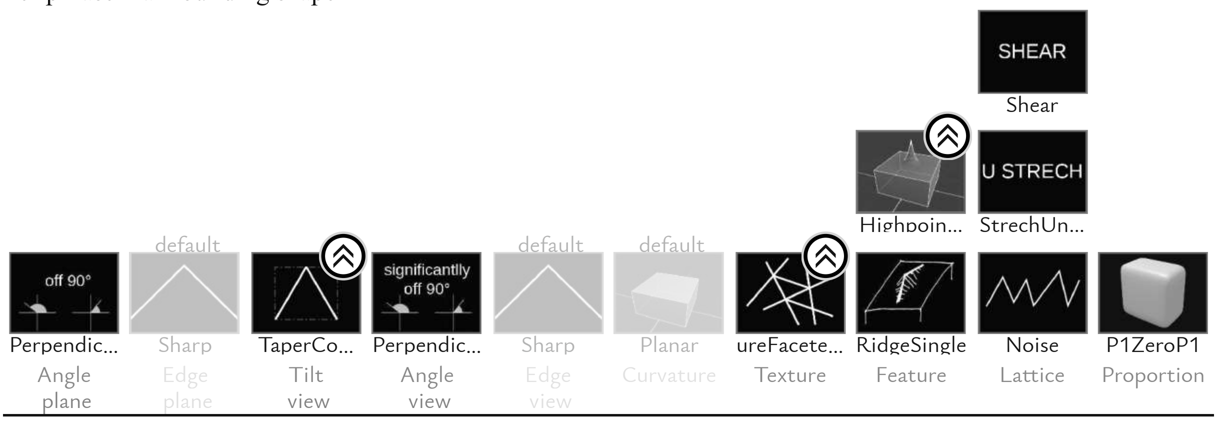
9. <StatesOfArchitectures_by NicLehoux> 2

Group:	B - Spike (Position: 5)	Year, City:	2010 Shanghai
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	lu
Empirical Id:	emp-n-lu	Brief:	Luxembourg
Internal Ids:	prj2142, rep184, itm203	Full:	Luxembourg Pavilion
Tags:	expo2010/n-pav-lu/nn-luxembourg	Qualified:	(see headline)

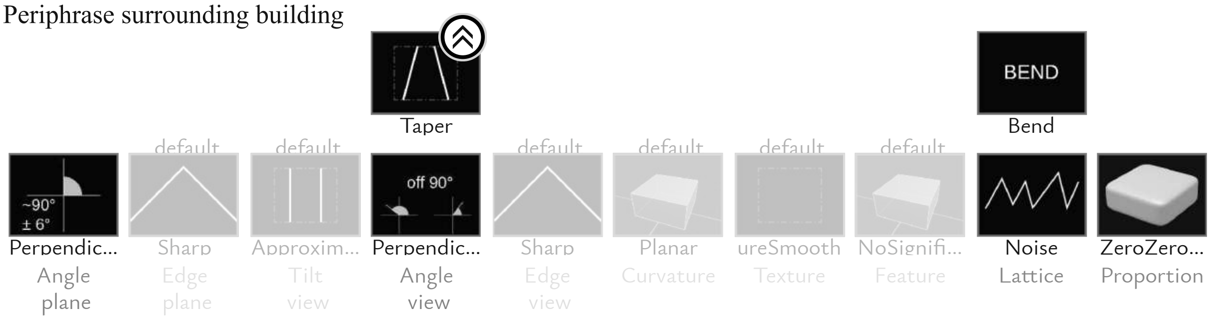
B5 - Expo 2010 Luxembourg Pavilion (Shanghai)



Periphrase main building shape



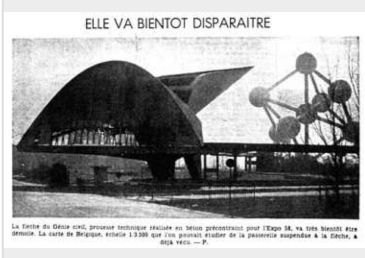
Periphrase surrounding building



B6 - Expo 1958 Fleche Du Genie Civil (Bruxelles)

1. <Flickr_userJohnClaudi> 11069025224_f6cc97a3d5_o

2. <WirtschaftswundermuseumDe> big_11049940_0_439-309



3. <Photobucket_userLemog> fleche_derniere_heure_01_04_1970_80

4. <Photobucket_userLemog> 58_det_arrow_01_original

5. <Wikipedia_byWouterhagens> Expo58_Belgie_kaart_A

6. <Flickr_userCentralebibliotheek> 4132518679_e7a4e00bfe_z

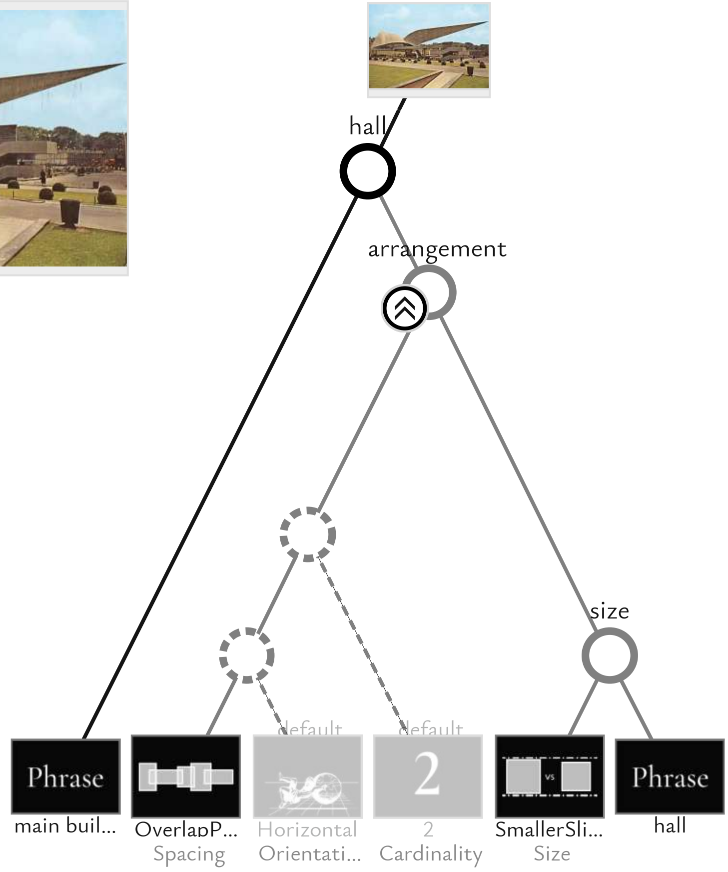
7. <Flickr_userCentralebibliotheek> 4133280070_f2bf71759e_z

8. <Flickr_userCentralebibliotheek> 4133280182_833dfc375c_z

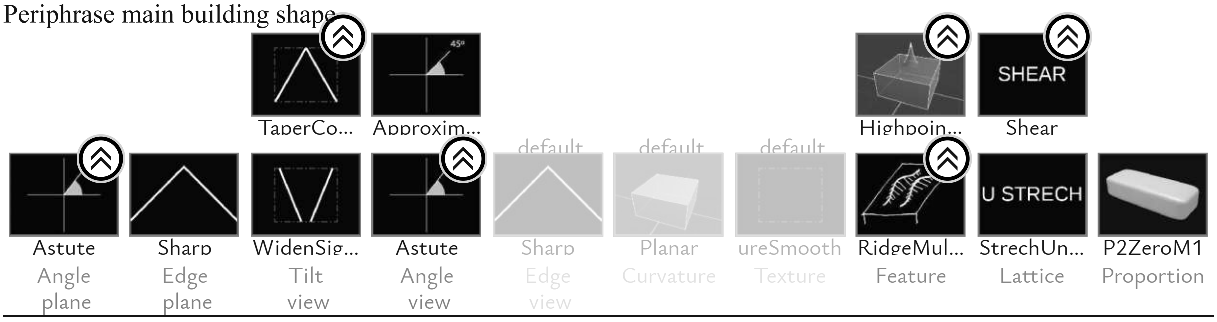
9. <Lemog3dBblogspot> wip_1958_Bruxelles_094_800

Group:	B - Spike (Position: 6)	Year, City:	1958 Bruxelles
Pavilion Type:	Corporate Pavilion (c-pav)	Shortest:	civ
Empirical Id:	emp-c-civil	Brief:	Civil Enginnering
Internal Ids:	prj3522, rep185, itm221	Full:	Fleche Du Genie Civil
Tags:	expo1958/c-pav/cn-flecheDuGenieCivil	Qualified:	(see headline)

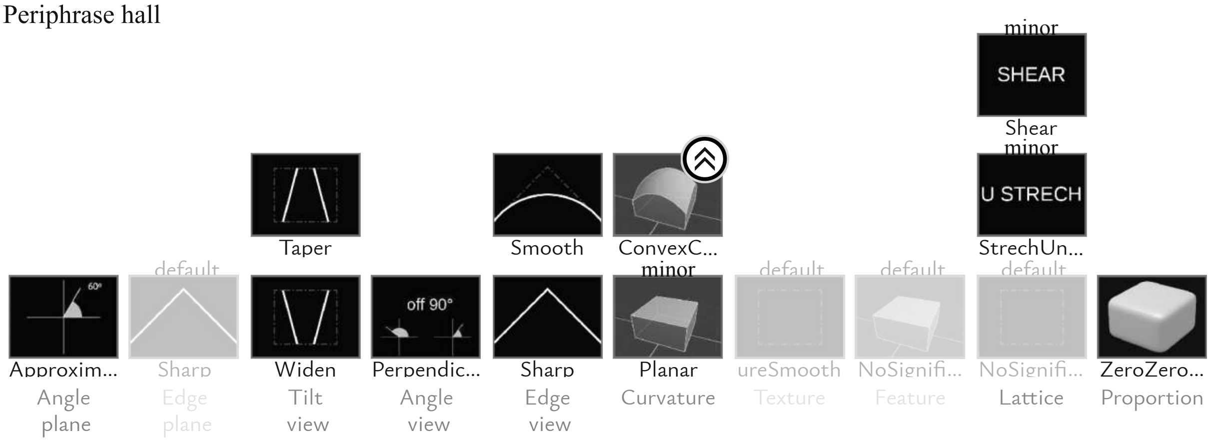
B6 - Expo 1958 Fleche Du Genie Civil (Bruxelles)



Periphrase main building shape



Periphrase hall



B7 - Expo 1958 Philips Corporate Pavilion (Bruxelles)


1. <ArchdailyCom_philipsPav> 1312860908-image-38


2. <ArchdailyCom_philipsPav> 1312860836-image-1


3. <Weltausstellungen>

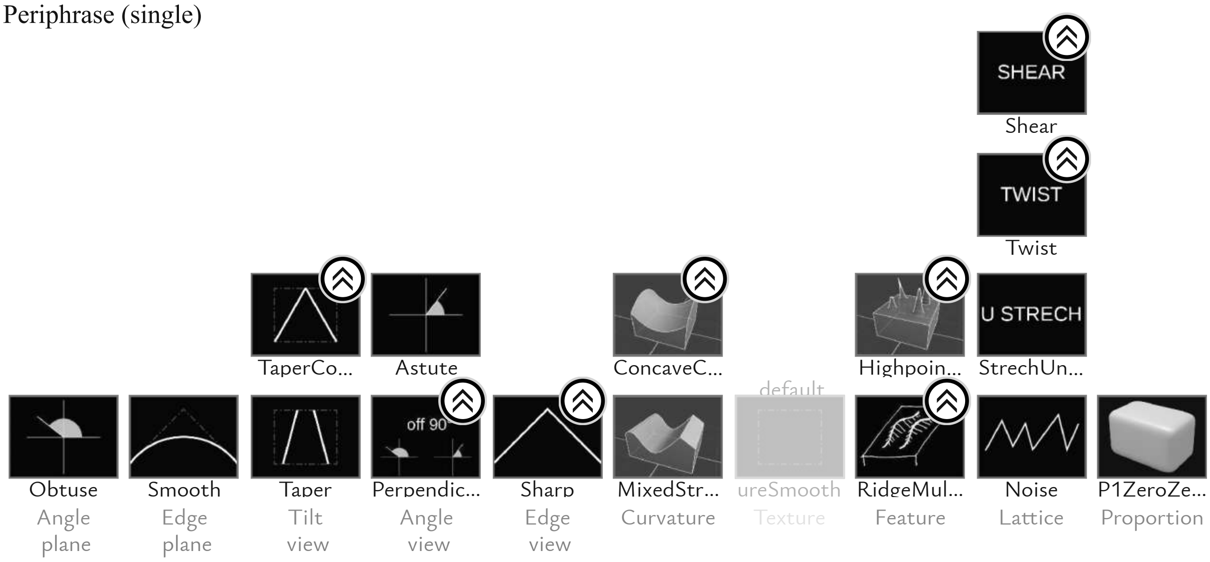

4. <Wikipedia_byWouterhagens> Expo58_building_Philips


5. <Weltausstellungen>


6. <ArchdailyCom_philipsPav> 1312860861-image-20

Group:	B - Spike (Position: 7)	Year, City:	1958 Bruxelles
Pavilion Type:	Corporate Pavilion (c-pav)	Shortest:	phil
Empirical Id:	emp-c-philips	Brief:	Philips
Internal Ids:	prj3523, rep186, itm178	Full:	Philips Corporate Pavilion
Tags:	expo1958/c-pav/cn-philips	Qualified:	(see headline)

Periphrase (single)



This page intentionally left blank in print layout

C1 - Expo 2010 Angola Pavilion (Shanghai)

1. <Flickr_userWojtekgurak> 5417727359_865fc7ae6f_o

2. <Flickr_userKimon> 4686486565_6519d11fed_o

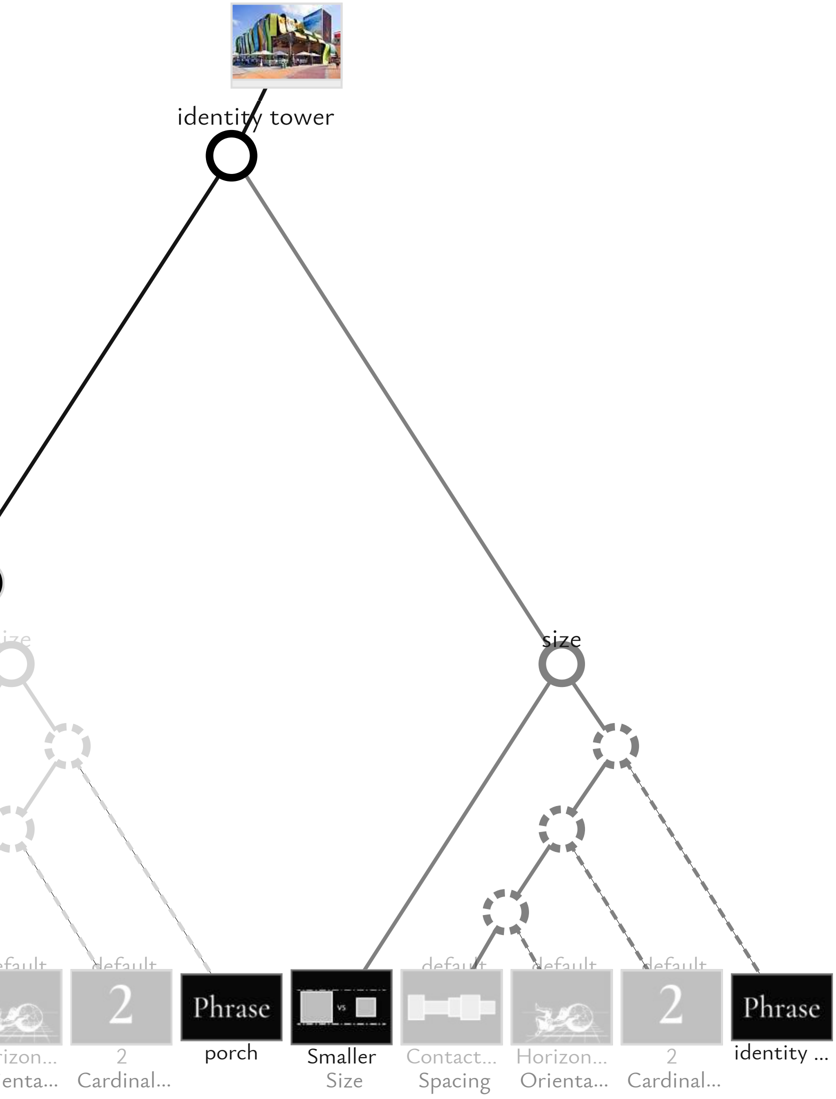
3. <Flickr_userAypexa> 4577499713_d9600ceacf_o

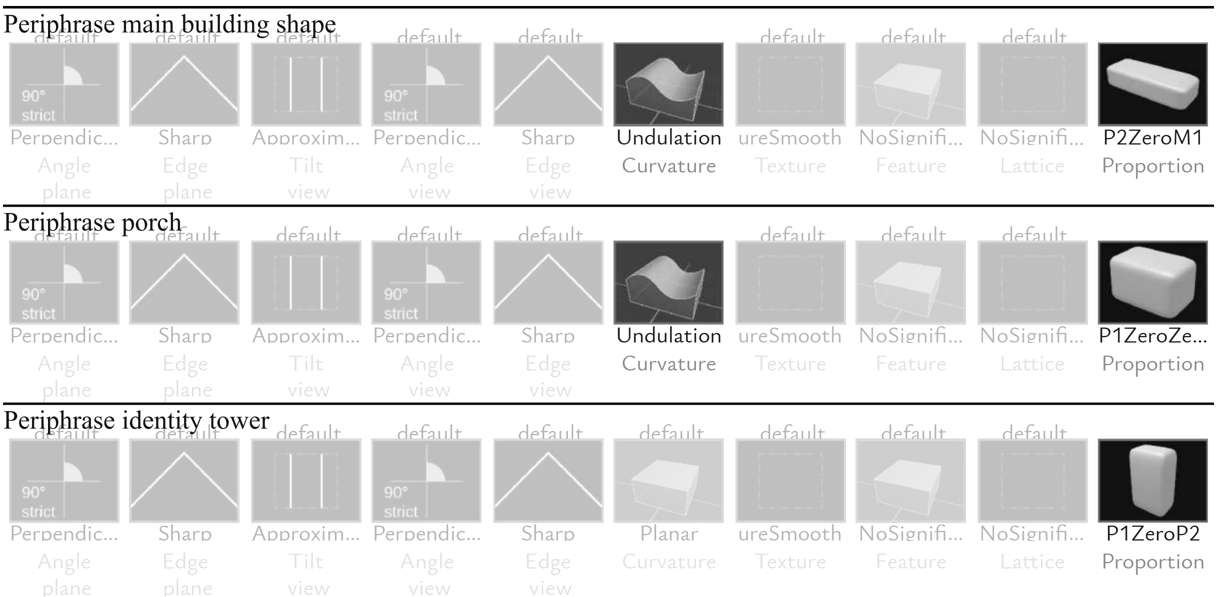
4. <BingMaps>

5. <Flickr_userKimon> 4694625896_ba5e42f657_o

Group:	C - Hidden Simple (Position: 1)	Year, City:	2010 Shanghai
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	ao
Empirical Id:	emp-n-ao	Brief:	Angola
Internal Ids:	prj2101, rep187, itm185	Full:	Angola Pavilion
Tags:	expo2010/n-pav-ao/nn-angola	Qualified:	(see headline)

C1 - Expo 2010 Angola Pavilion (Shanghai)





C2 - Expo 2010 Algeria Pavilion (Shanghai)

1. <Flickr_userFrankschacht> 4997424655_73ecd09a48_b

2. <Flickr_userFrankschacht> 4997488663_01f65a889f_b

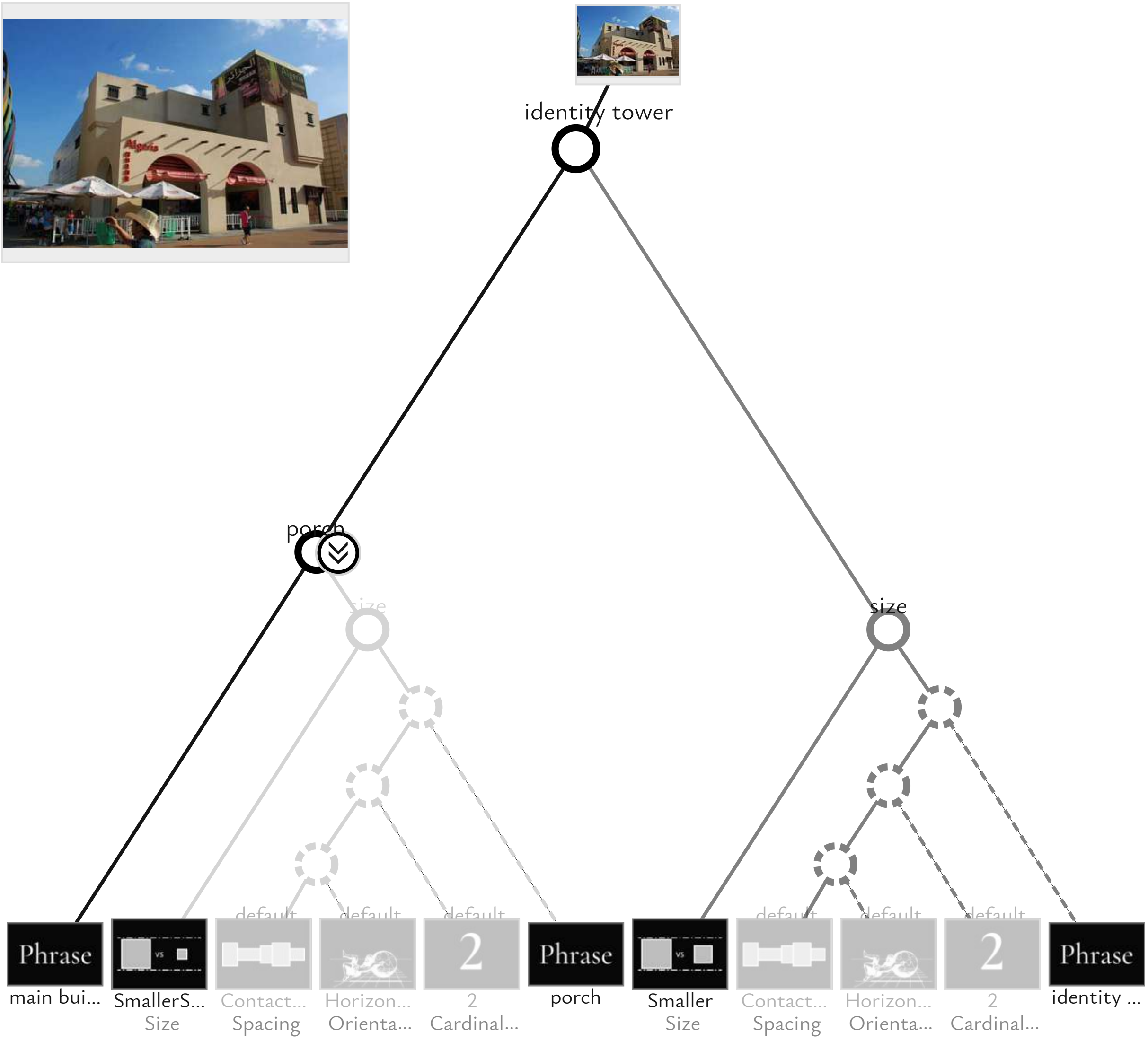
3. <Flickr_userDisneykid> 5531307918_d3431b426e_b

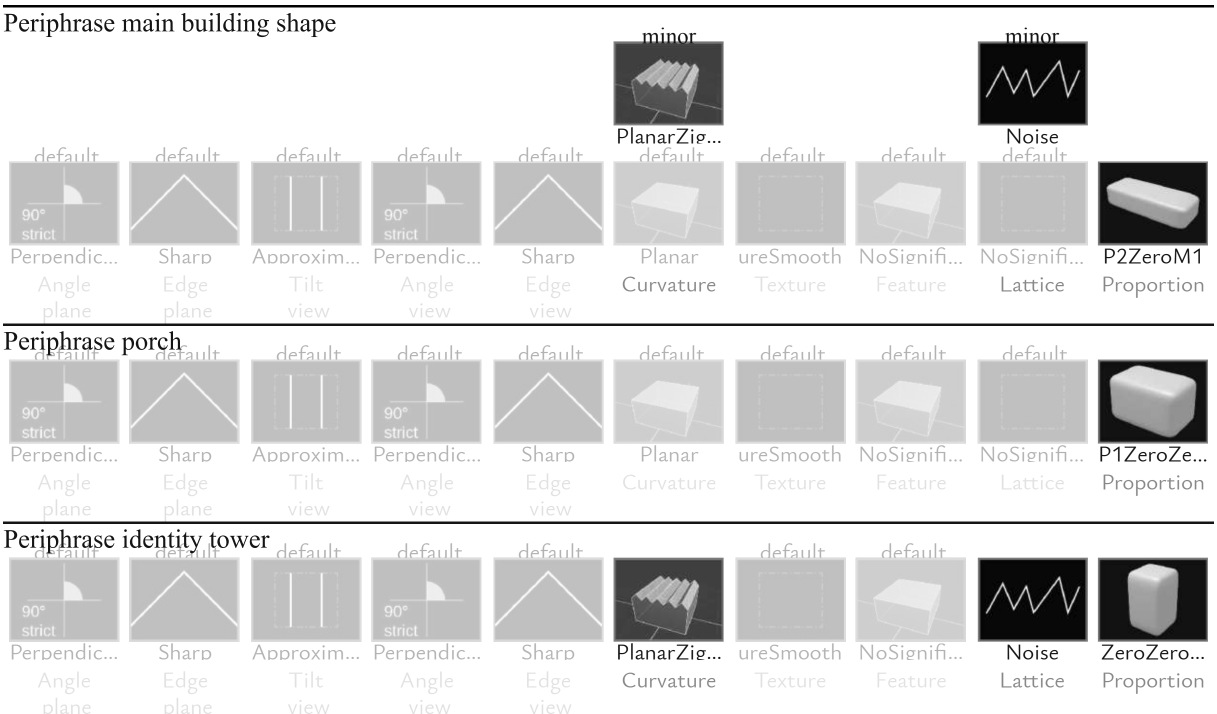
4. <BingMaps>

5. <Flickr_userKimon> 4686486979_ae4df71e17_o

Group:	C - Hidden Simple (Position: 2)	Year, City:	2010 Shanghai
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	dz
Empirical Id:	emp-n-dz	Brief:	Algeria
Internal Ids:	prj2118, rep199, itm254	Full:	Algeria Pavilion
Tags:	expo2010/n-pav-dz/nn-algeria	Qualified:	(see headline)

C2 - Expo 2010 Algeria Pavilion (Shanghai)





C3 - Expo 1967 France Pavilion (Montreal)


1. <ArchivesdemontrealIcaAtomOrg> VM94-B253-014


2. <ArchivesdemontrealIcaAtomOrg> VM94-B253-009


3. <ArchivesdemontrealIcaAtomOrg> VM94-EX136-426


4. <ArchivesdemontrealIcaAtomOrg> VM94-EX136-425


5. <ArchivesdemontrealIcaAtomOrg> VM94-EX136-419


6. <ArchivesdemontrealIcaAtomOrg> VM94-EX131-002

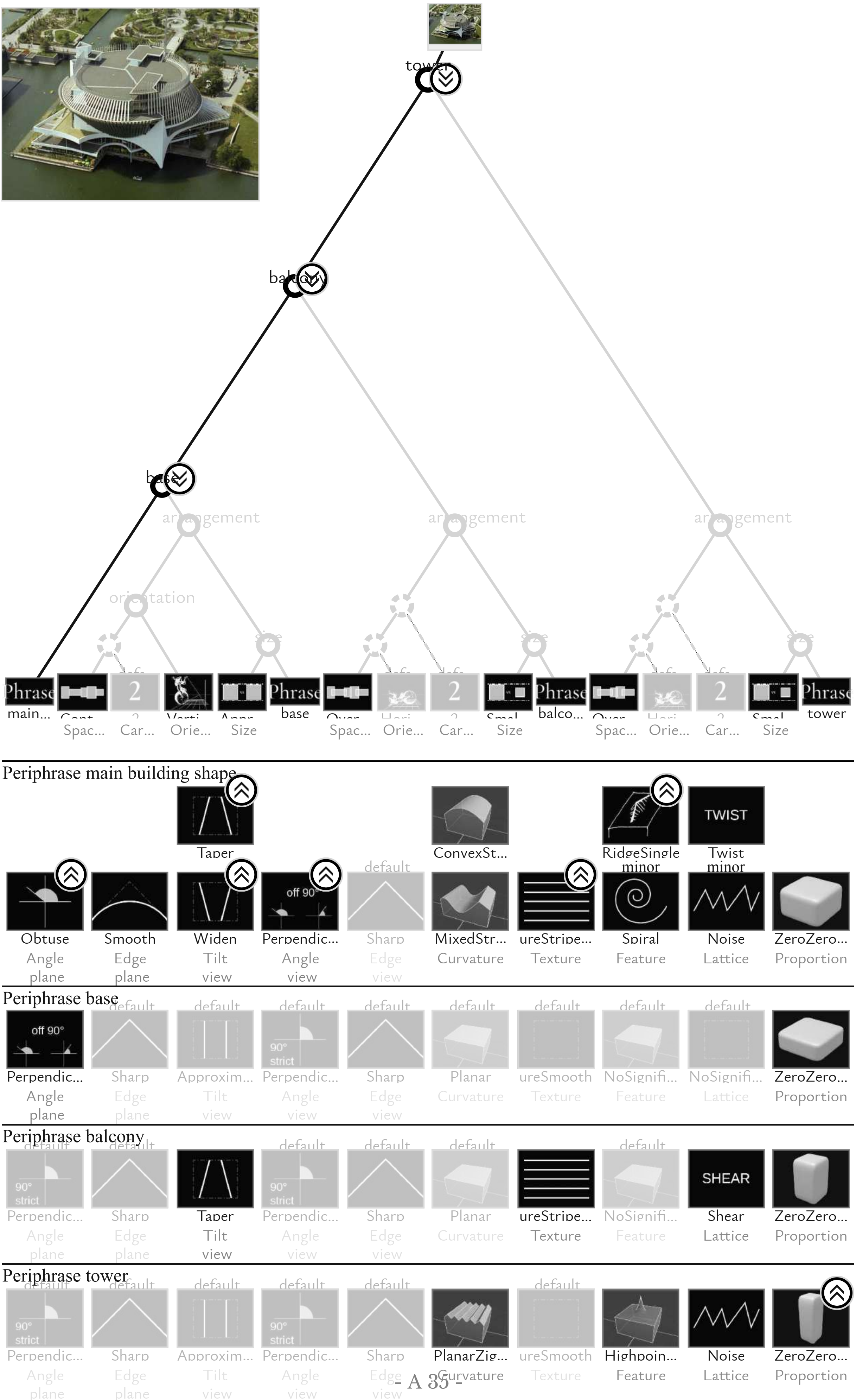

7. <Flickr_userBdutfield> 3091383352_b94b1e334d_o


8. <RobertLavigneCom> 21_R0701_FR


9. <ArchivesdemontrealIcaAtomOrg> VM94-B253-022

Group:	C - Hidden Simple (Position: 3)	Year, City:	1967 Montreal
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	fr67
Empirical Id:	emp-n-fr67	Brief:	France (1967)
Internal Ids:	prj2409, rep203, itm184	Full:	France Pavilion (1967)
Tags:	expo1967/n-pav-fr/nn-france	Qualified:	(see headline)

C3 - Expo 1967 France Pavilion (Montreal)



C4 - Expo 2010 Monaco Pavilion (Shanghai)

1. <Flickr_userFrankschacht> 4663059809_26d8f763eb_b

2. <Flickr_userWentaoYin12> 5549429045_4bc42996fc_o

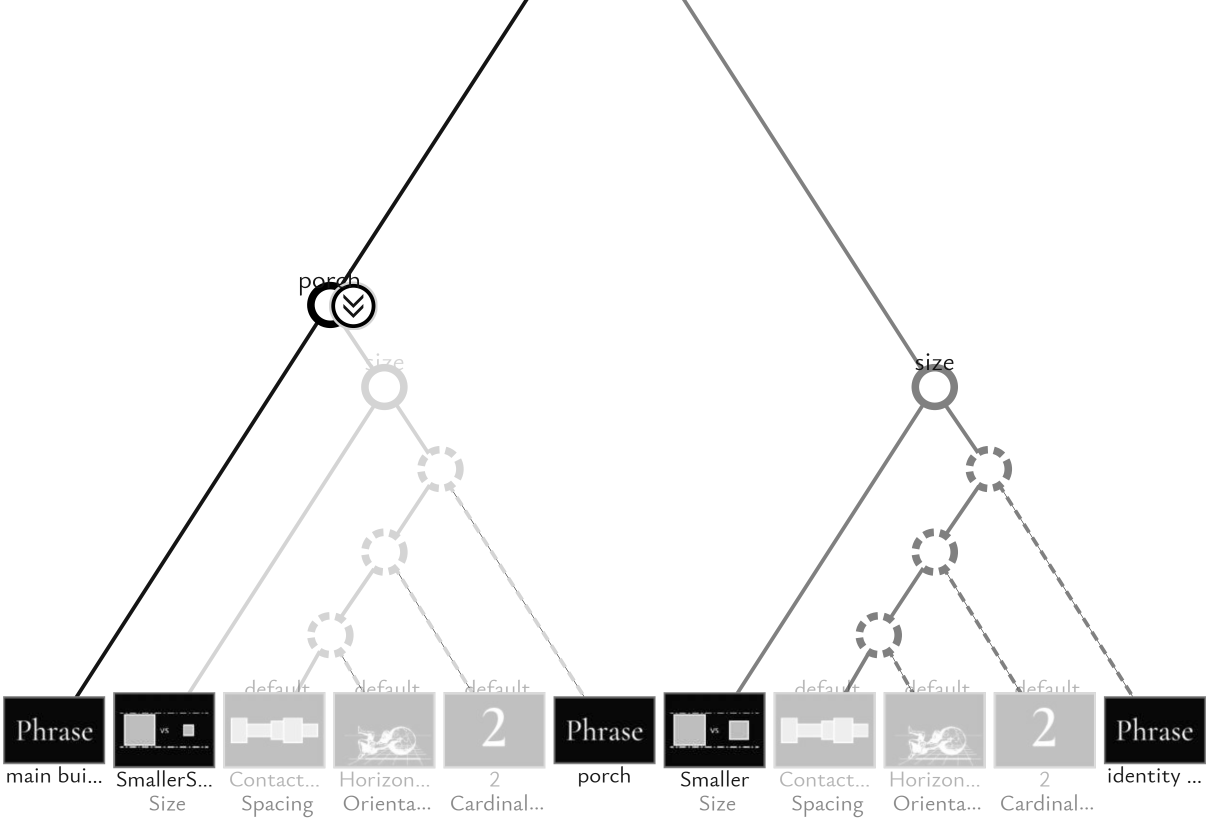
3. <Panoramio_user1400530_(utf8_1961)> 37447469

4. <Expo2010ShanghaiChinaFromTheAir> 113

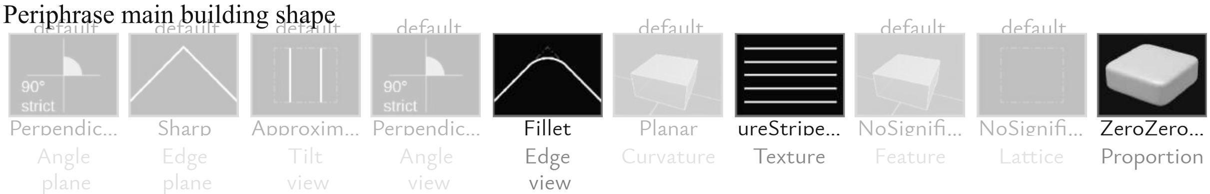
5. <BingMaps>

Group:	C - Hidden Simple (Position: 4)	Year, City:	2010 Shanghai
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	mc
Empirical Id:	emp-n-mc	Brief:	Monaco
Internal Ids:	prj2146, rep202, itm241	Full:	Monaco Pavilion
Tags:	expo2010/n-pav-mc/nn-monaco	Qualified:	(see headline)

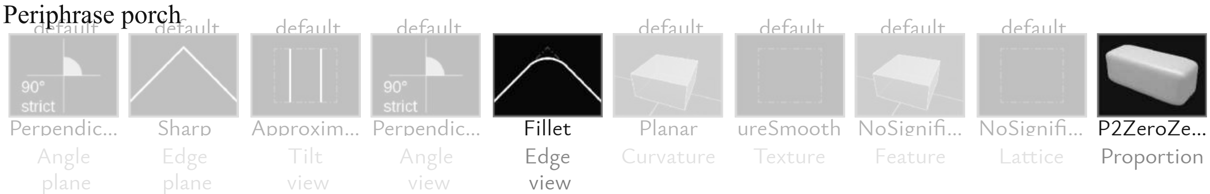
C4 - Expo 2010 Monaco Pavilion (Shanghai)



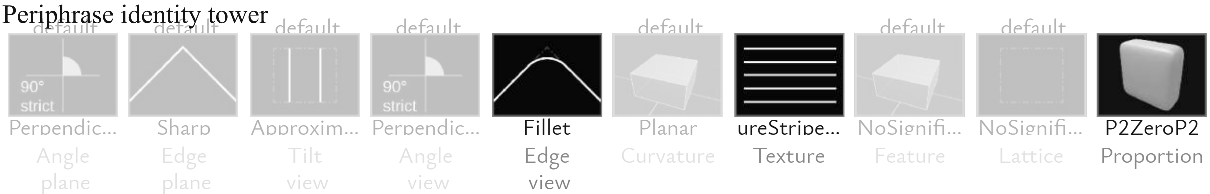
Periphrase main building shape



Periphrase porch



Periphrase identity tower



C5 - Expo 2010 Israel Pavilion (Shanghai)

1. <Flickr_userWojtekgurak> 5466772900_2a9d7895b3_o

2. <Flickr_userWojtekgurak> 5466175155_0119072b8a_o

3. <Expo2010ShanghaiChinaFromTheAir> expo0002

4. <Flickr_userExpomuseum> 4399956881_b3a5e64057_o

5. <Flickr_userWentaoYin12> 5517345302_2cf707dc4d_o

6. <BingMaps>

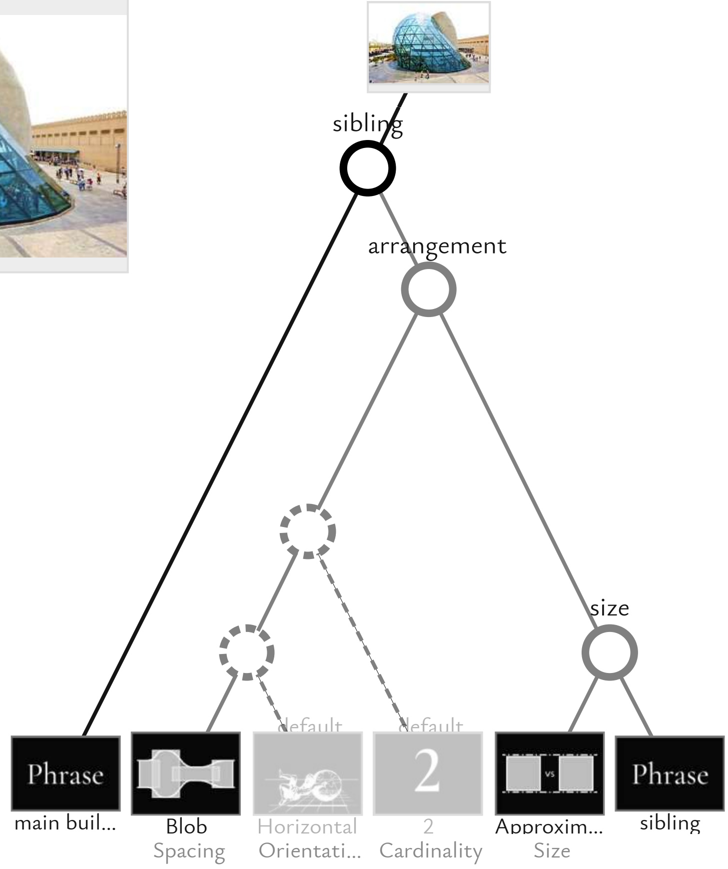
7. <Flickr_userExpomuseum> 4794627105_24560b3404_o

8. <Flickr_userWentaoYin12> 5516728691_9a8319ea9d_o

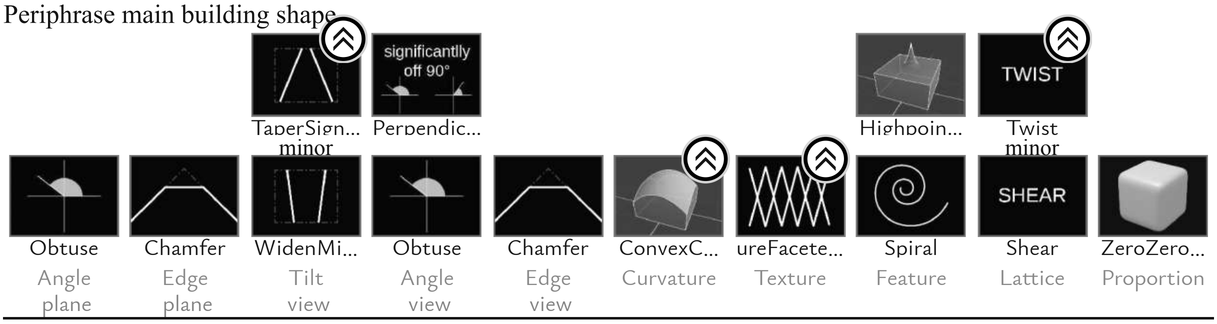
9. <Flickr_userWentaoYin12> 5517345302_2cf707dc4d_o

Group:	C - Hidden Simple (Position: 5)	Year, City:	2010 Shanghai
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	il
Empirical Id:	emp-n-il	Brief:	Israel
Internal Ids:	prj2129, rep194, itm232	Full:	Israel Pavilion
Tags:	expo2010/n-pav-il/nn-israel	Qualified:	(see headline)

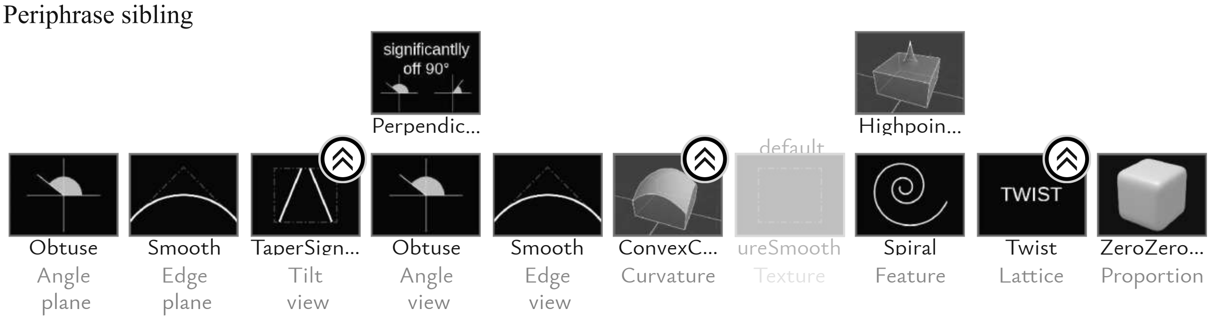
C5 - Expo 2010 Israel Pavilion (Shanghai)



Periphrase main building shape



Periphrase sibling



C6 - Expo 2010 Croatia Pavilion (Shanghai)

1. <Flickr_userKimon> 4691922765_26d9673878_o

2. <Flickr_userFrankschacht> 4992703825_a697e68fdb_b

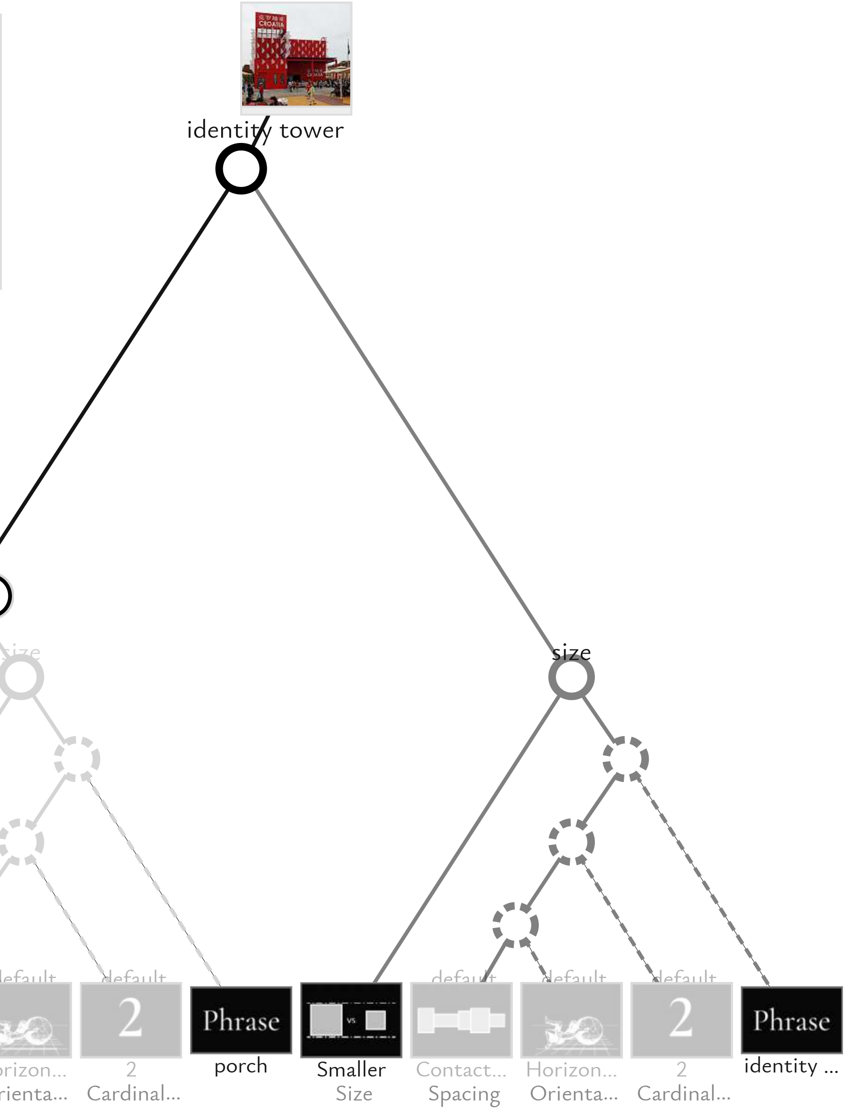
3. <Flickr_userSnapshotunlimited> 4608431937_c2d92acb19_b

4. <BingMaps>

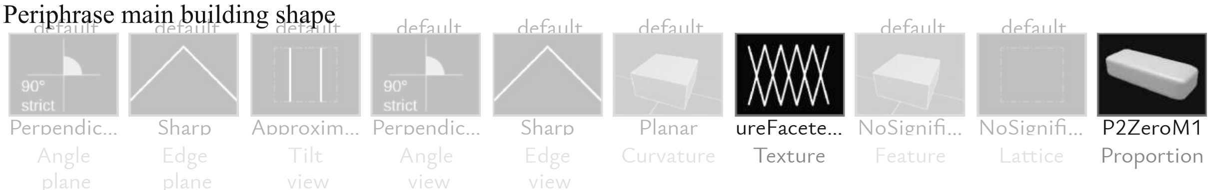
5. <PJ> 1040771

Group:	C - Hidden Simple (Position: 6)	Year, City:	2010 Shanghai
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	hr
Empirical Id:	emp-n-hr	Brief:	Croatia
Internal Ids:	prj2125, rep188, itm177	Full:	Croatia Pavilion
Tags:	expo2010/n-pav-hr/nn-croatia	Qualified:	(see headline)

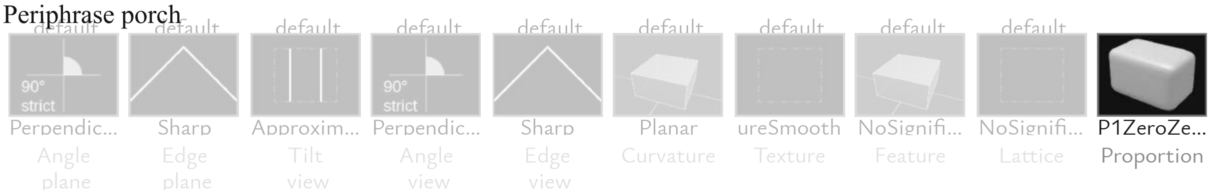
C6 - Expo 2010 Croatia Pavilion (Shanghai)



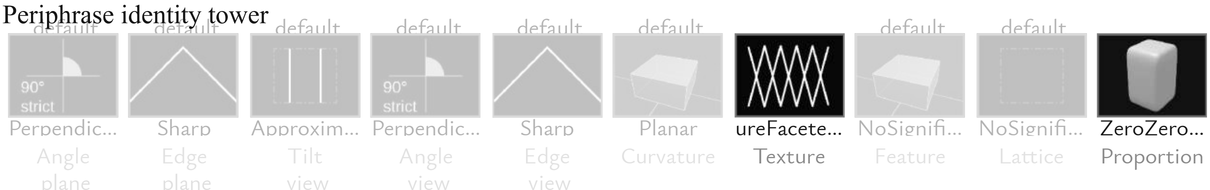
Periphrase main building shape



Periphrase porch



Periphrase identity tower



C7 - Expo 2010 Sri Lanka Pavilion (Shanghai)

1. <Flickr_userGavinbloys> 5679031723_faf51d6206_o

2. <Flickr_userFrankschacht> 4699372649_bfae68b093_b

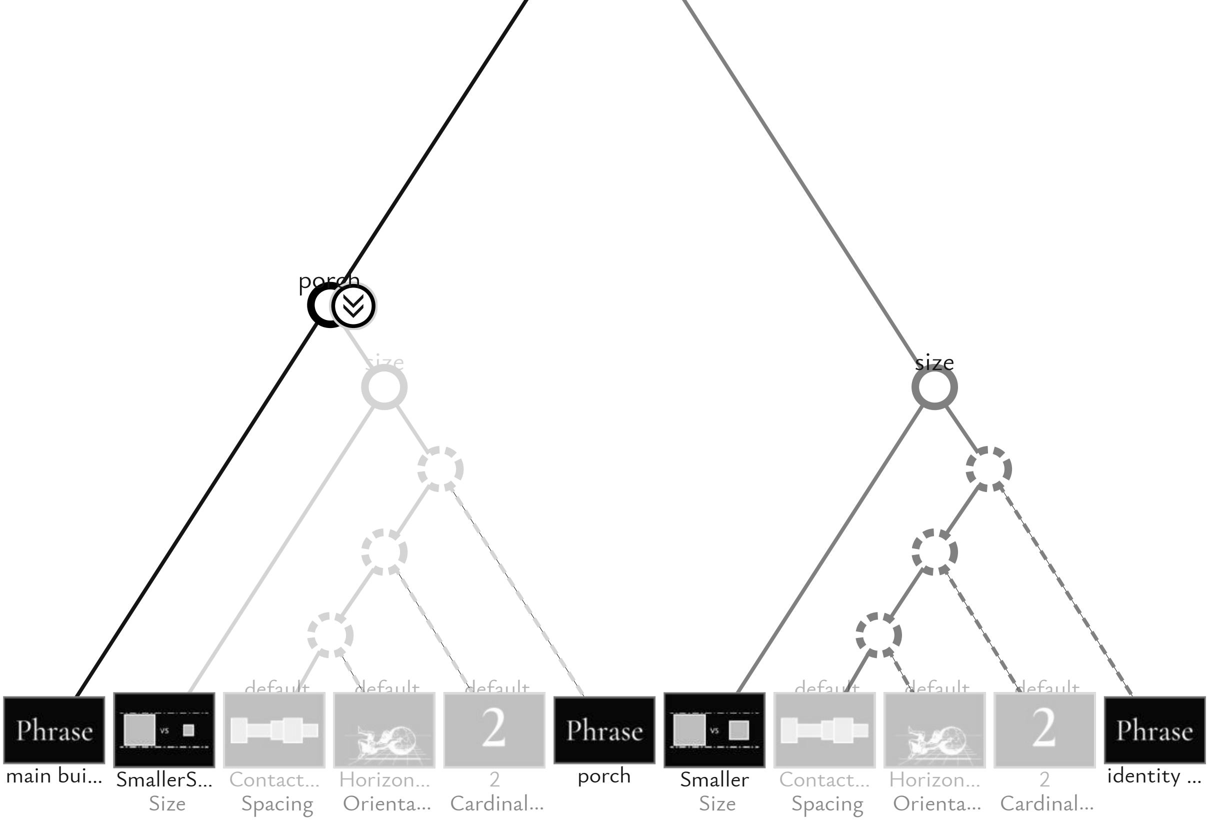
3. <Flickr_userFrankschacht> 4700005632_2484930b94_b

4. <BingMaps>

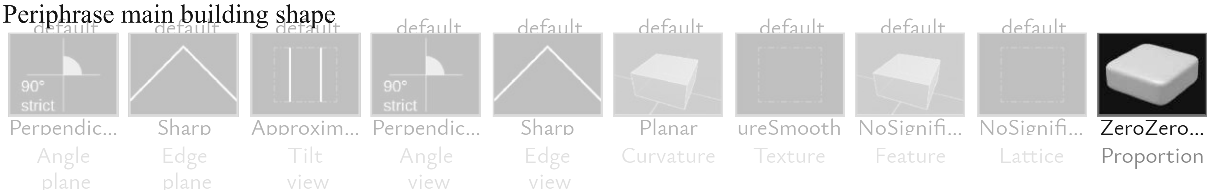
5. <Flickr_userDisneykid> 5420270823_635f0e46d2_b

Group:	C - Hidden Simple (Position: 7)	Year, City:	2010 Shanghai
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	lk
Empirical Id:	emp-n-lk	Brief:	Sri Lanka
Internal Ids:	prj2140, rep190, itm234	Full:	Sri Lanka Pavilion
Tags:	expo2010/n-pav-lk/nn-sriLanka	Qualified:	(see headline)

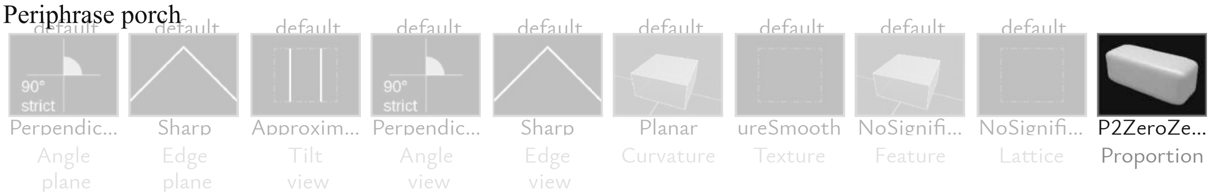
C7 - Expo 2010 Sri Lanka Pavilion (Shanghai)



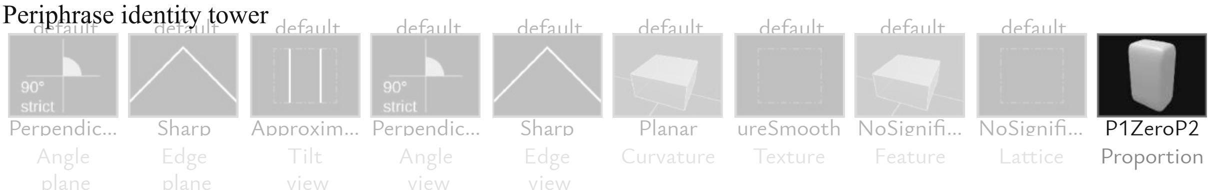
Periphrase main building shape



Periphrase porch

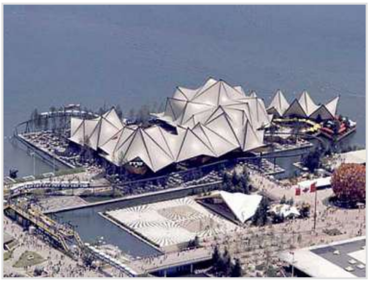


Periphrase identity tower



D1 - Expo 1967 Ontario Region Pavilion (Montreal)


1. <Flickr_userMagstb67> 8218671921_930da04a04_o


2. <CollectionscanadaGcCa> e000990835


3. <Flickr_userMagstb67> 2532455673_a04aec434e_o


4. <Flickr_userMagstb67> 2534967030_ac99c24fa1_o


5. <Flickr_userBdutfield> 3091394202_0d48d1e178_o


6. <CollectionscanadaGcCa> e000996019

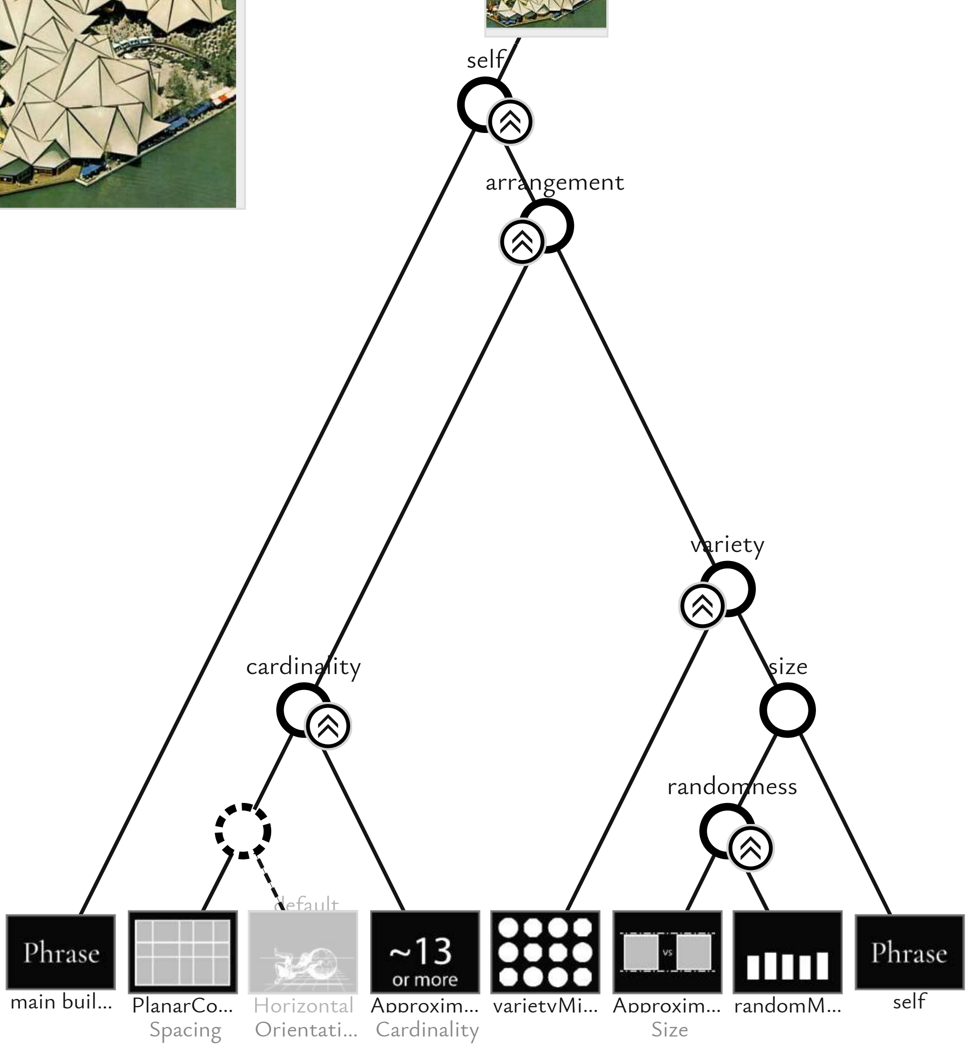

7. <CollectionscanadaGcCa> e000990833


8. <ArchivesdemontrealIcaAtomOrg> VM94-EX136-212

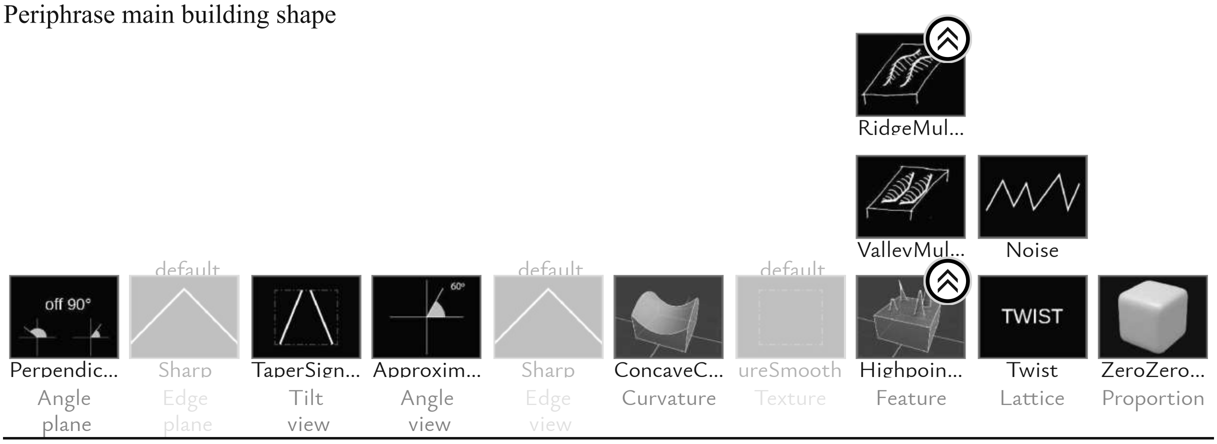

9. <GbphotodidacticalCa> Photo-Expo-67-35-Ontario-Place

Group:	D - Multiple (Position: 1)	Year, City:	1967 Montreal
Pavilion Type:	Region Pavilion (r-pav)	Shortest:	ont
Empirical Id:	emp-r-ont	Brief:	Ontario
Internal Ids:	prj2354, rep191, itm246	Full:	Ontario Region Pavilion
Tags:	expo1967/r-pav/rn-ontario	Qualified:	(see headline)

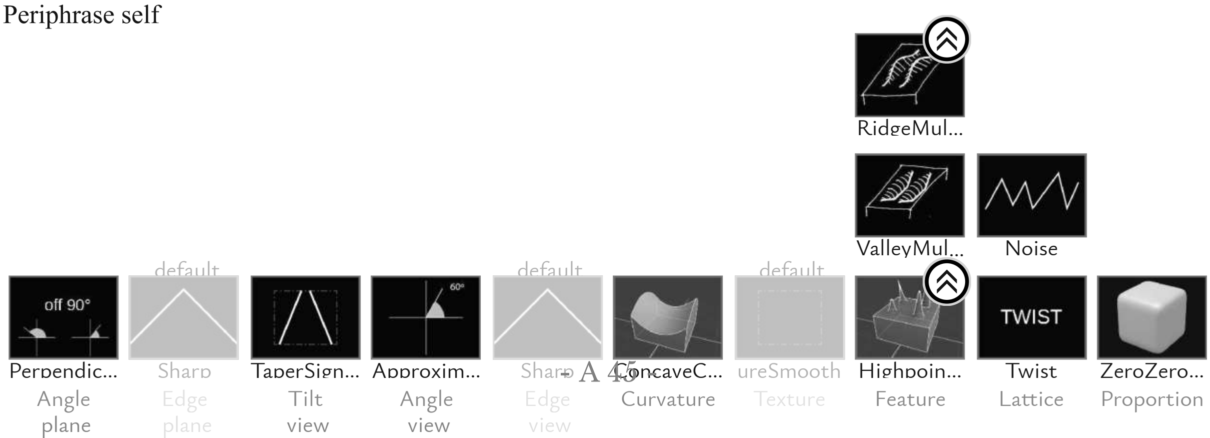
D1 - Expo 1967 Ontario Region Pavilion (Montreal)



Periphrase main building shape



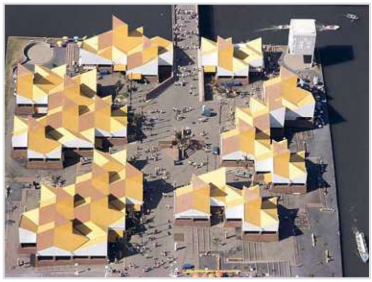
Periphrase self



D2 - Expo 1967 Africa Group Pavilion (Montreal)

1. <CollectionscanadaGcCa> e 000990843

2. <CollectionscanadaGcCa> e 000990844



3. <CollectionscanadaGcCa> e 000990840

4. <Expo67NcfCa> african-pavilion-at-expo67-man-and-his-world

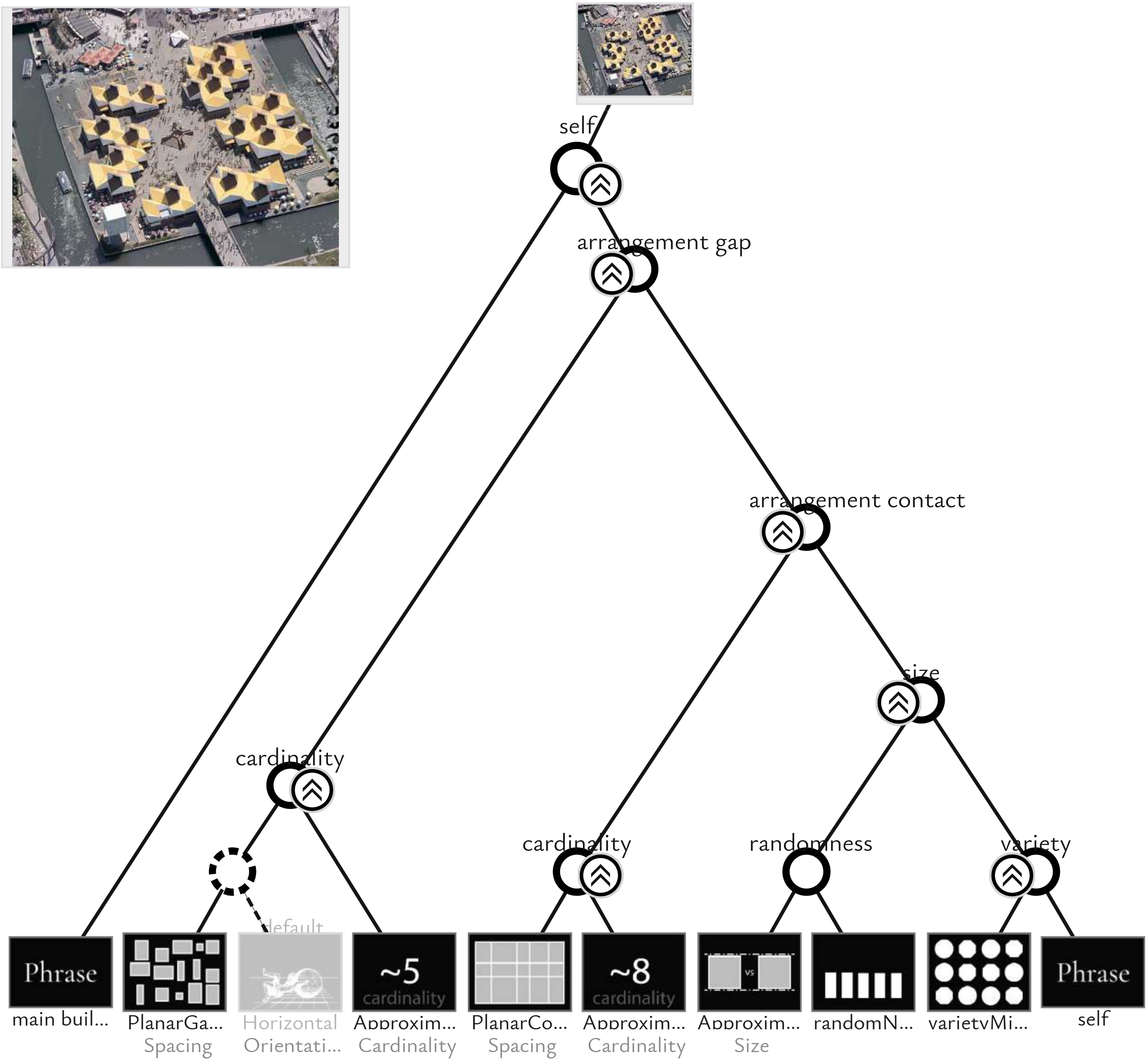
5. <ArchivesdemontrealIcaAtomOrg> VM94-EX281-071

6. <Flickr_userBdutfield> 3090631217_878d1684bc_o

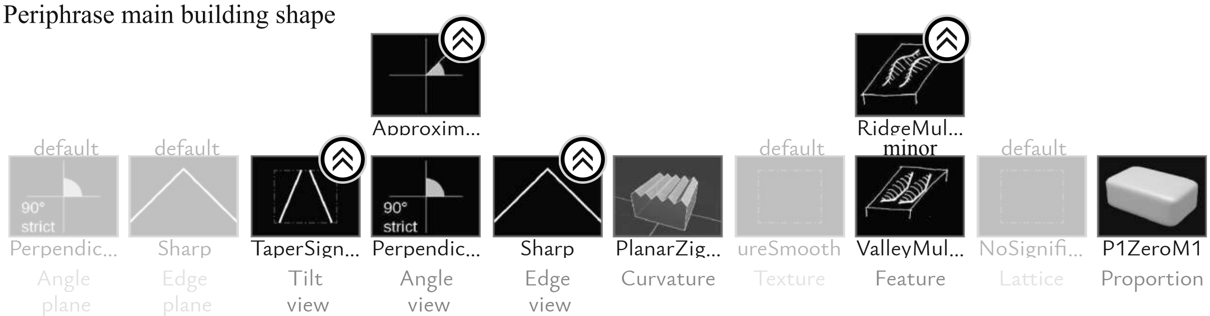
7. <Flickr_userBdutfield> 3090626031_8efde6fa83_o

Group:	D - Multiple (Position: 2)	Year, City:	1967 Montreal
Pavilion Type:	Group Pavilion (g-pav)	Shortest:	africa
Empirical Id:	emp-g-africa	Brief:	Africa
Internal Ids:	prj2511, rep192, itm228	Full:	Africa Group Pavilion
Tags:	expo1967/g-pav/gn-africa	Qualified:	(see headline)

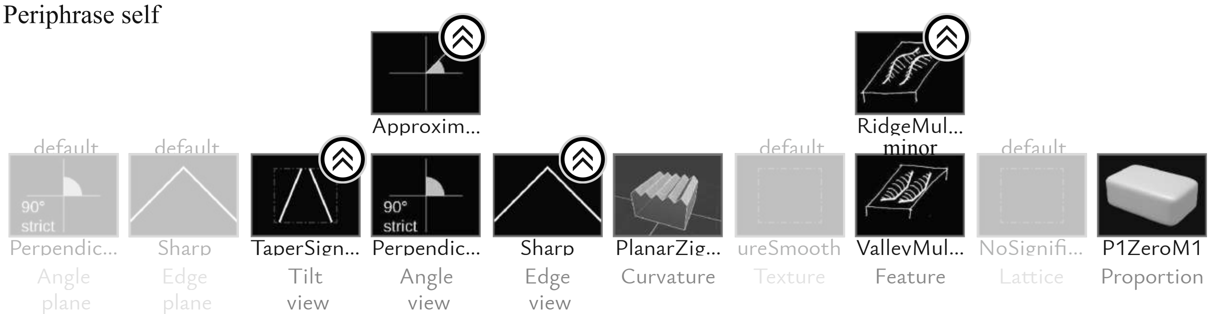
D2 - Expo 1967 Africa Group Pavilion (Montreal)



Periphrase main building shape



Periphrase self



D3 - Expo 1967 Pulp and Paper Corporate Pav. (Montreal)

1. <Flickr_userThePieShopsCollection> 3750276283_26d3059f98_b

2. <ArchivesdemontrealIcaAtomOrg> VM94-EX114-001

3. <Expo67NcfCa> expo67_pulp_and_paper_construction

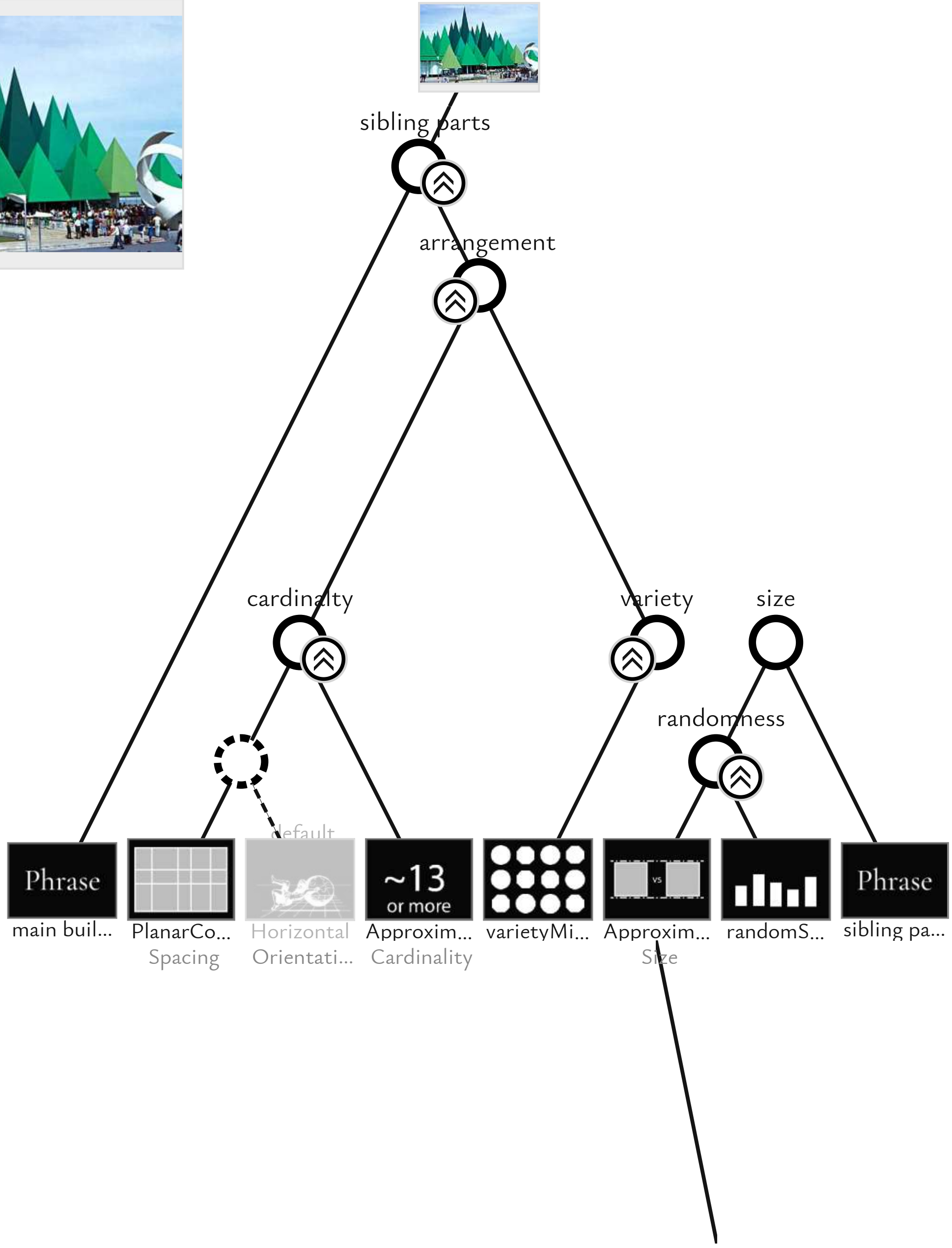
4. <CollectionscanadaGcCa> e000990845

5. <ArchivesdemontrealIcaAtomOrg> VM94-EX281-017

6. <ArchivesdemontrealIcaAtomOrg> VM94-EX220-004

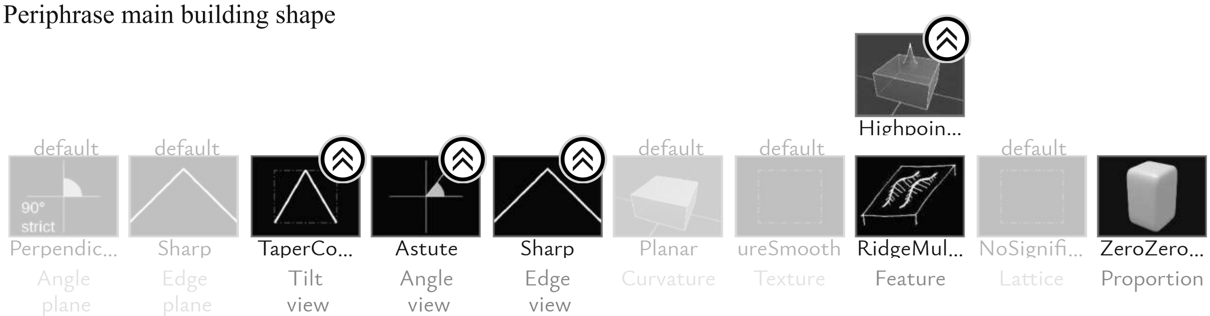
Group:	D - Multiple (Position: 3)	Year, City:	1967 Montreal
Pavilion Type:	Corporate Pavilion (c-pav)	Shortest:	pulp
Empirical Id:	emp-c-pulp	Brief:	Pulp and Paper
Internal Ids:	prj2569, rep193, itm250	Full:	Pulp and Paper Corporate Pavilion
Tags:	expo1967/c-pav/cn-pulpAndPaper	Qualified:	(see headline)

D3 - Expo 1967 Pulp and Paper Corporate Pav. (Montreal)

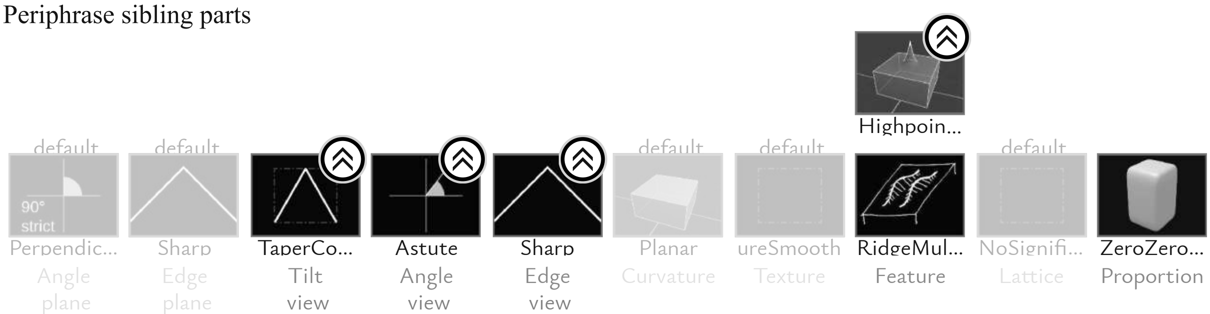


D3 - Expo 1967 Pulp and Paper Corporate Pav. (Montreal)

Periphrase main building shape



Periphrase sibling parts



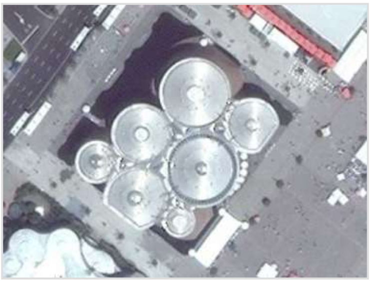
This page intentionally left blank in print layout

D4 - Expo 2010 Wanke Corporate Pavilion (Shanghai)


1. <PJ> 1040415

2. <Expo2010ShanghaiChinaFromTheAir> expo0047c


3. <Panoramio_user1400530_(utf81961)> 37531715


4. <BingMaps>


5. <PJ> 1040432


6. <Expo2010ShanghaiChinaFromTheAir> 139

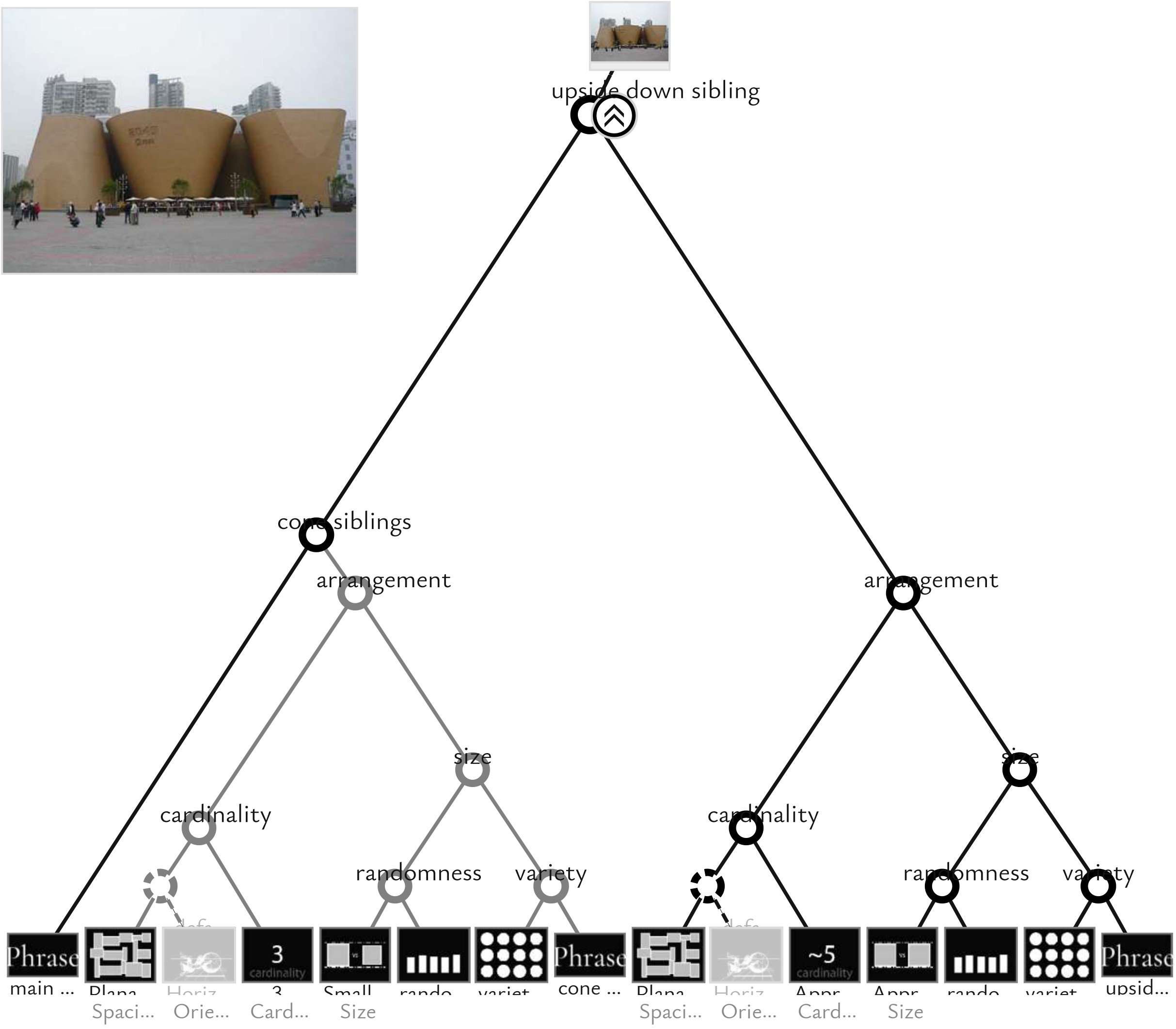

7. <Flickr_userKimon> 4633134741_3ed5dbdd4d_o


8. <Flickr_userExpomuseum> 4782706384_acefd2c72b_o

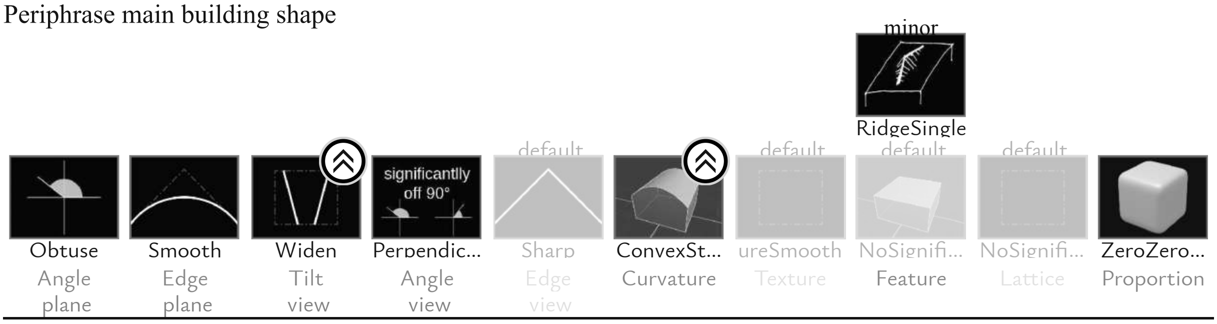

9. <PJ> 1040427

Group:	D - Multiple (Position: 4)	Year, City:	2010 Shanghai
Pavilion Type:	Corporate Pavilion (c-pav)	Shortest:	wan
Empirical Id:	emp-c-wanke	Brief:	Wanke
Internal Ids:	prj2277, rep204, itm222	Full:	Wanke Corporate Pavilion
Tags:	expo2010/c-pav/cn-wanke2049	Qualified:	(see headline)

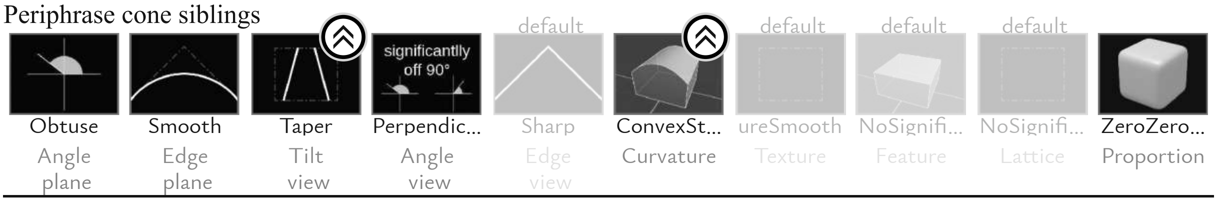
D4 - Expo 2010 Wanke Corporate Pavilion (Shanghai)



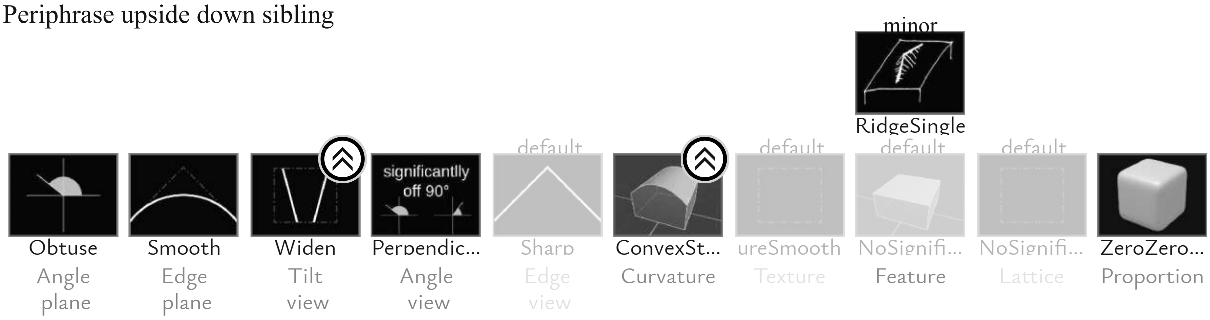
Periphrase main building shape



Periphrase cone siblings



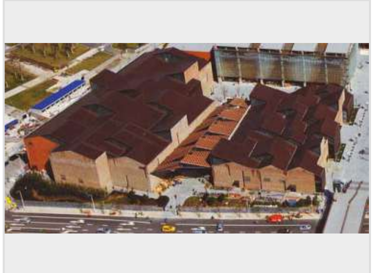
Periphrase upside down sibling



D5 - Expo 2010 Cases Theme Pavilion (Shanghai)


1. <Expo2010ShanghaiChinaFromTheAir> expo0046


2. <GoogleMaps>


3. <Expo2010ShanghaiChinaFromTheAir> 183


4. <Panoramio_user1400530_(utf81961)> 37531891

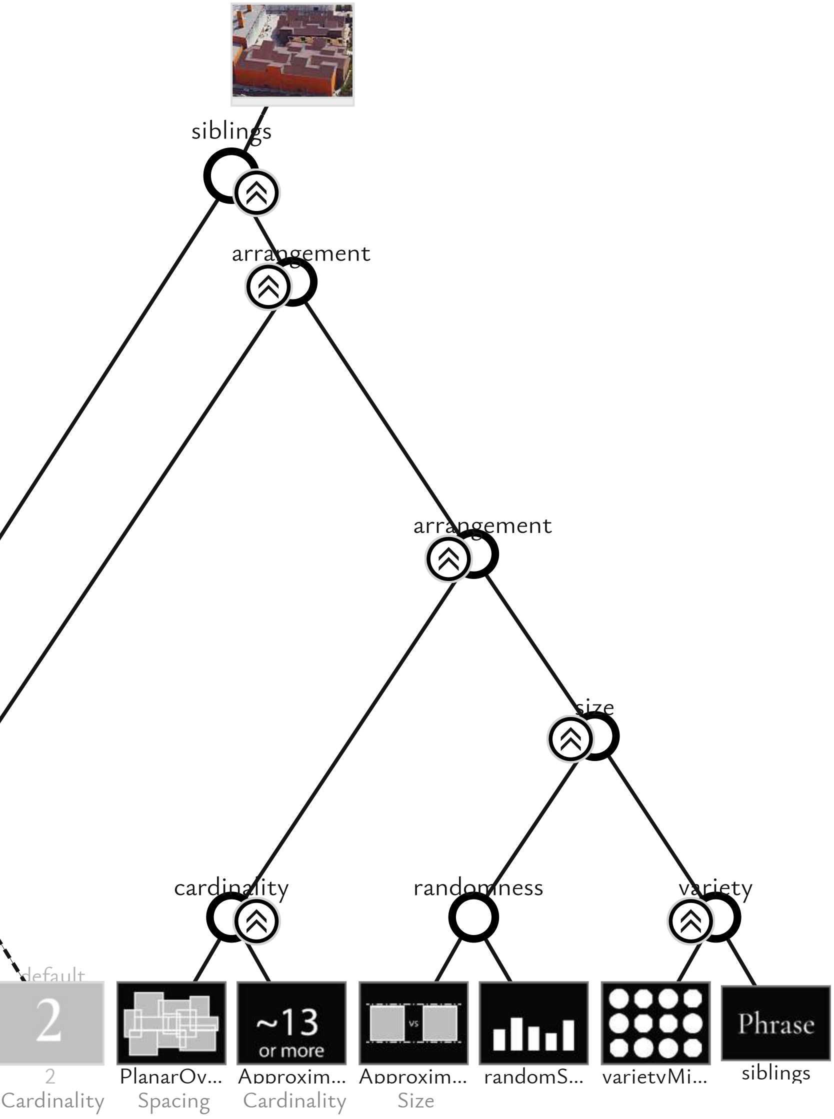

5. <Flickr_userWentaoYin12> 5398586380_52c33bc20d_o


6. <Panoramio_user1400530_(utf81961)> 37531972

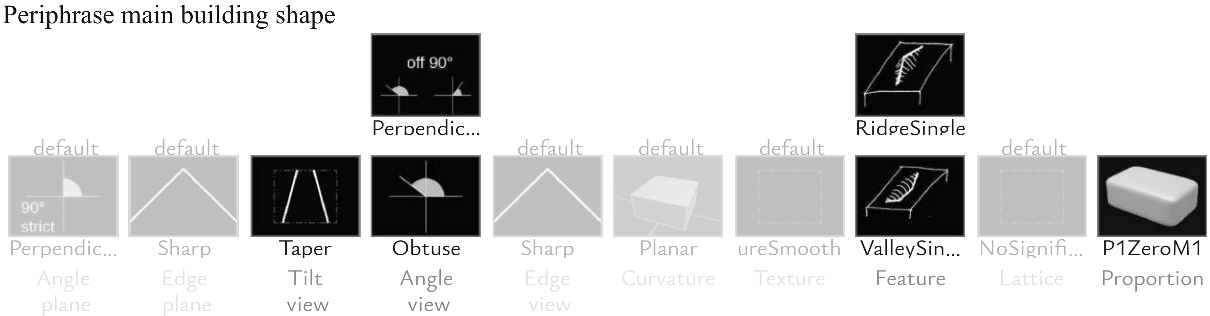

7. <Expo2010ShanghaiChinaFromTheAir> 137

Group:	D - Multiple (Position: 5)	Year, City:	2010 Shanghai
Pavilion Type:	Theme Pavilion (t-pav)	Shortest:	cas
Empirical Id:	emp-t-cases	Brief:	Cases
Internal Ids:	prj2225, rep195, itm259	Full:	Cases Theme Pavilion
Tags:	expo2010/t-pav/tn-cases4a	Qualified:	(see headline)

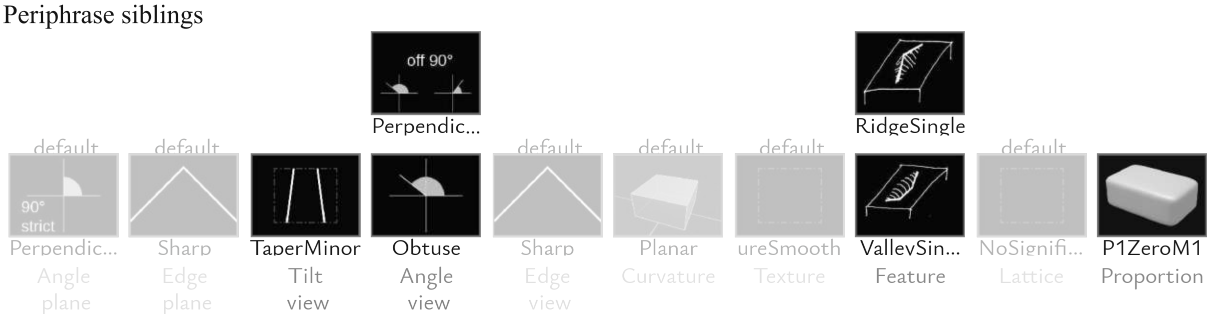
D5 - Expo 2010 Cases Theme Pavilion (Shanghai)



Periphrase main building shape



Periphrase siblings

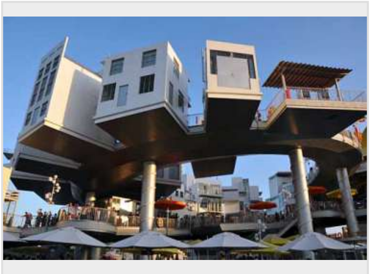


D6 - Expo 2010 Netherlands Pavilion (Shanghai)

1. <Expo2010ShanghaiChinaFromTheAir> expo0027

2. <Panoramio_user3962419_(DuyiHan)> 49651343

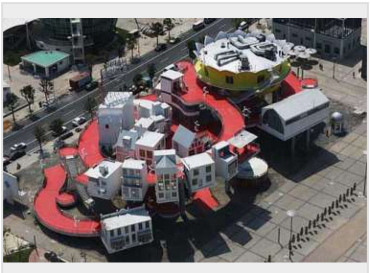
3. <Flickr_userFrankschacht> 4856567544_0d3bc25c8c_b



4. <Flickr_userPicturenarrative> 4969950220_a311aae176_b

5. <Flickr_userWojtekgurak> 5429069999_ae923f8282_o

6. <Flickr_userChazhutton> 4553652867_f2075f4394_o



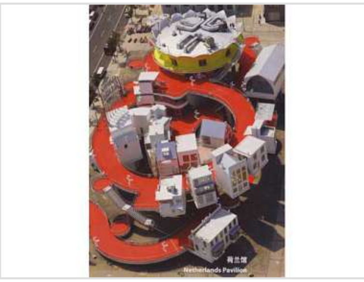
7. <11tecomBlog163Com_byAFP> Shanghai_Expo--5--600x400

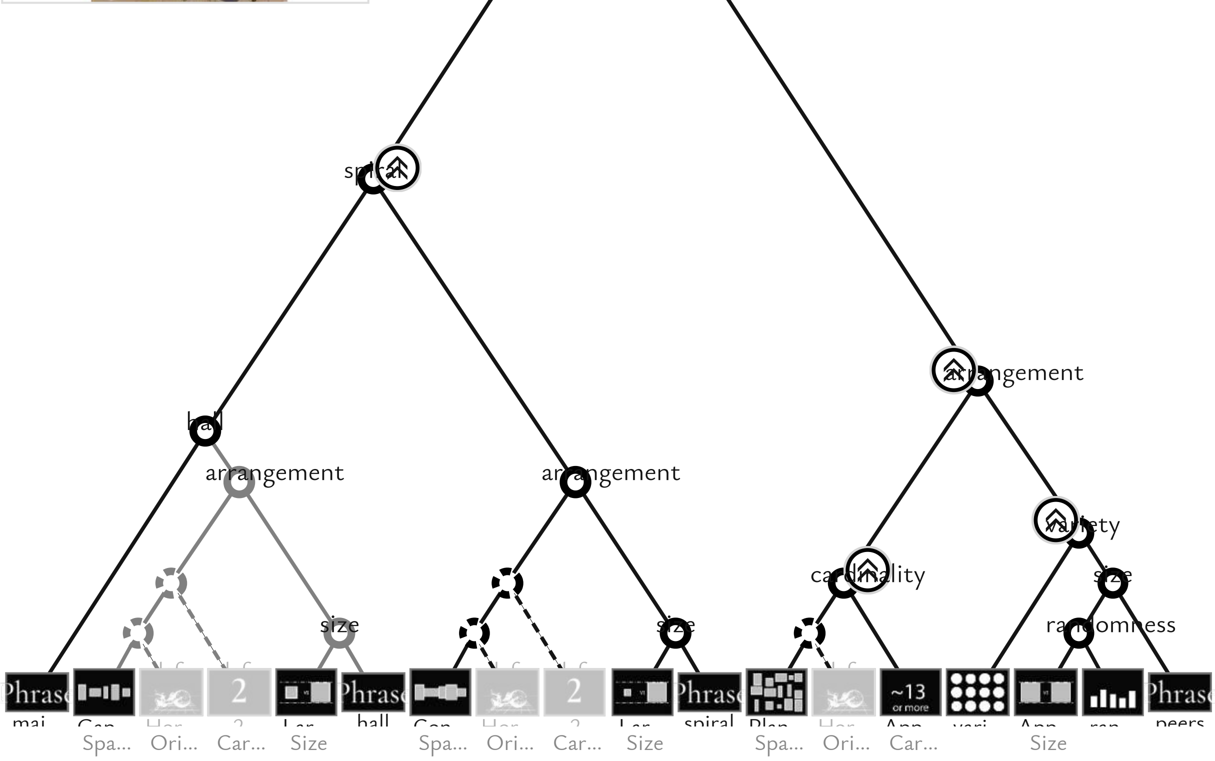
8. <Flickr_userChimaybleue> 4735137368_b8a08b9959_b

9. <Flickr_userExpomuseum> 4705083122_a280e98c54_o

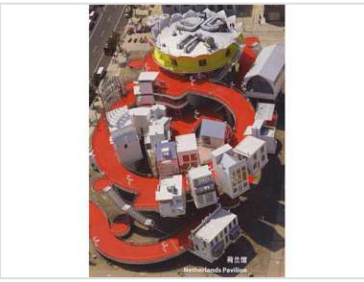
Group:	D - Multiple (Position: 6)	Year, City:	2010 Shanghai
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	nl10
Empirical Id:	emp-n-nl10	Brief:	Netherlands (2010)
Internal Ids:	prj2150, rep196, itm251	Full:	Netherlands Pavilion (2010)
Tags:	expo2010/n-pav-nl/nn-netherlands	Qualified:	(see headline)

D6 - Expo 2010 Netherlands Pavilion (Shanghai)

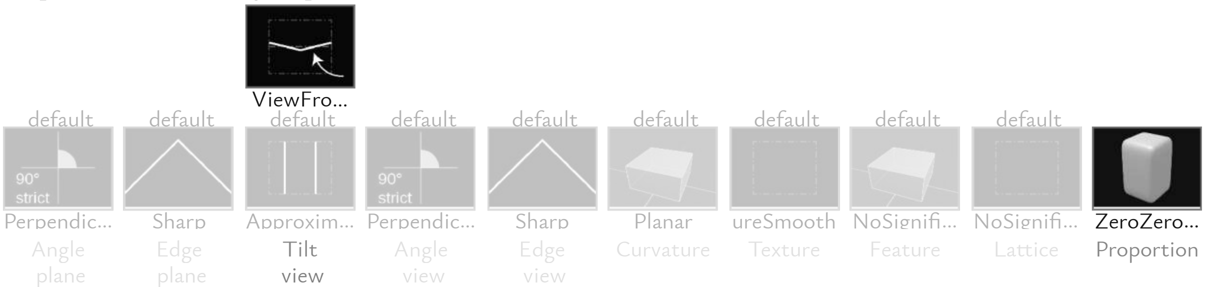




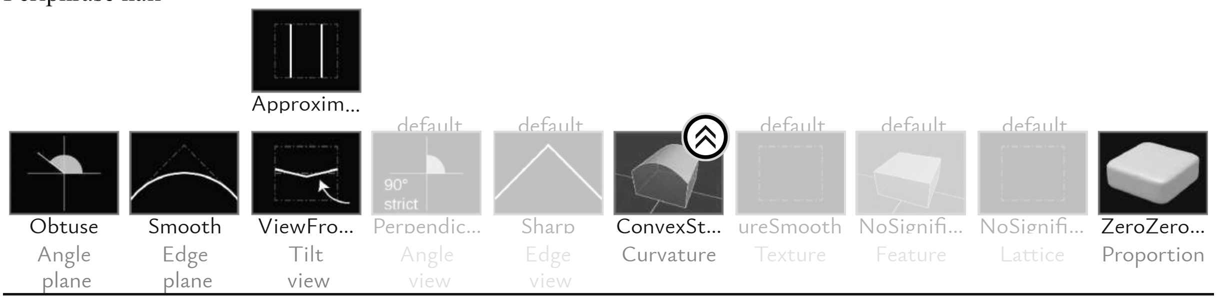
D6 - Expo 2010 Netherlands Pavilion (Shanghai)



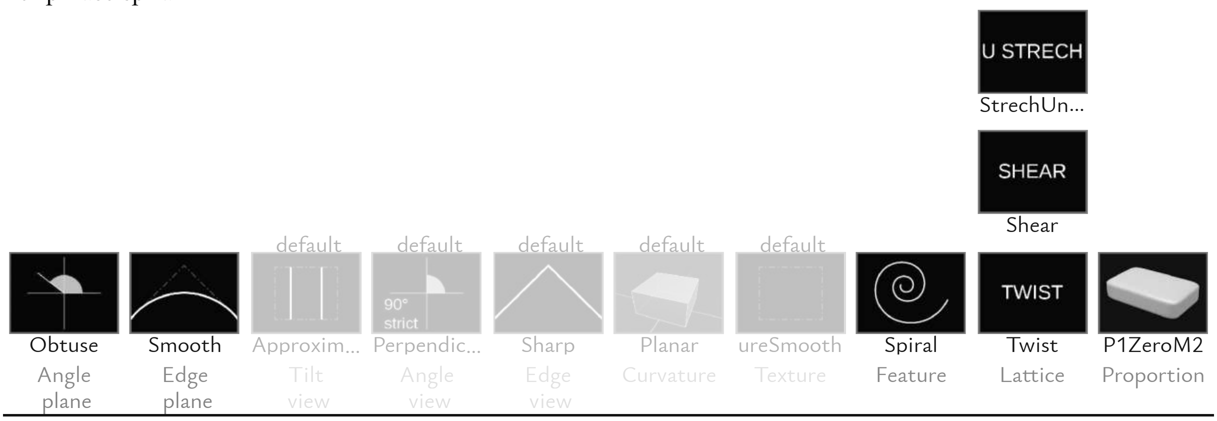
Periphrase main building shape



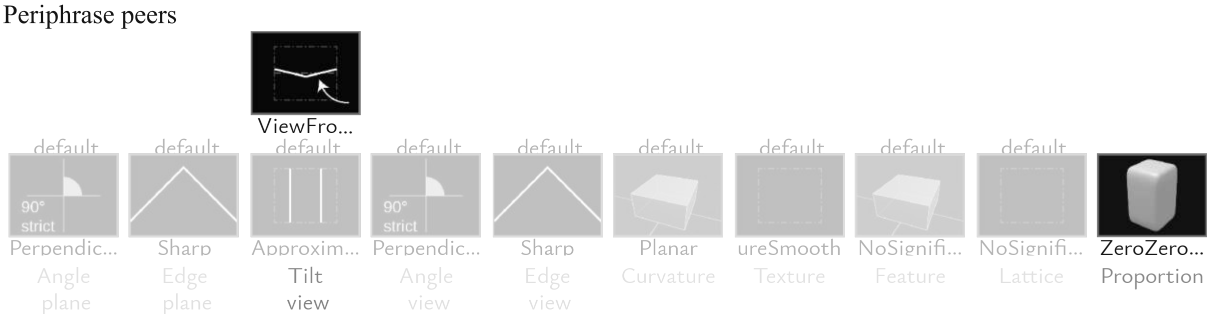
Periphrase hall



Periphrase spiral



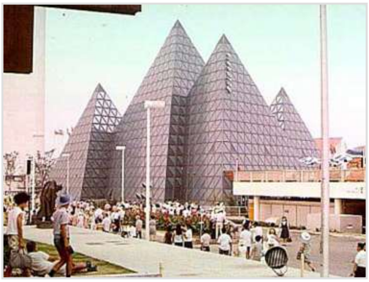
Periphrase peers



This page intentionally left blank in print layout

D7 - Expo 1970 Bulgaria Pavilion (Osaka)

1. <Flickr_userKOota> 5798600785_f0040bc9e6_o



2. <Bobp31HomesteadCom_byBobProcter> expo70_3

3. <NiftyComSaekiSin> b623burugaria

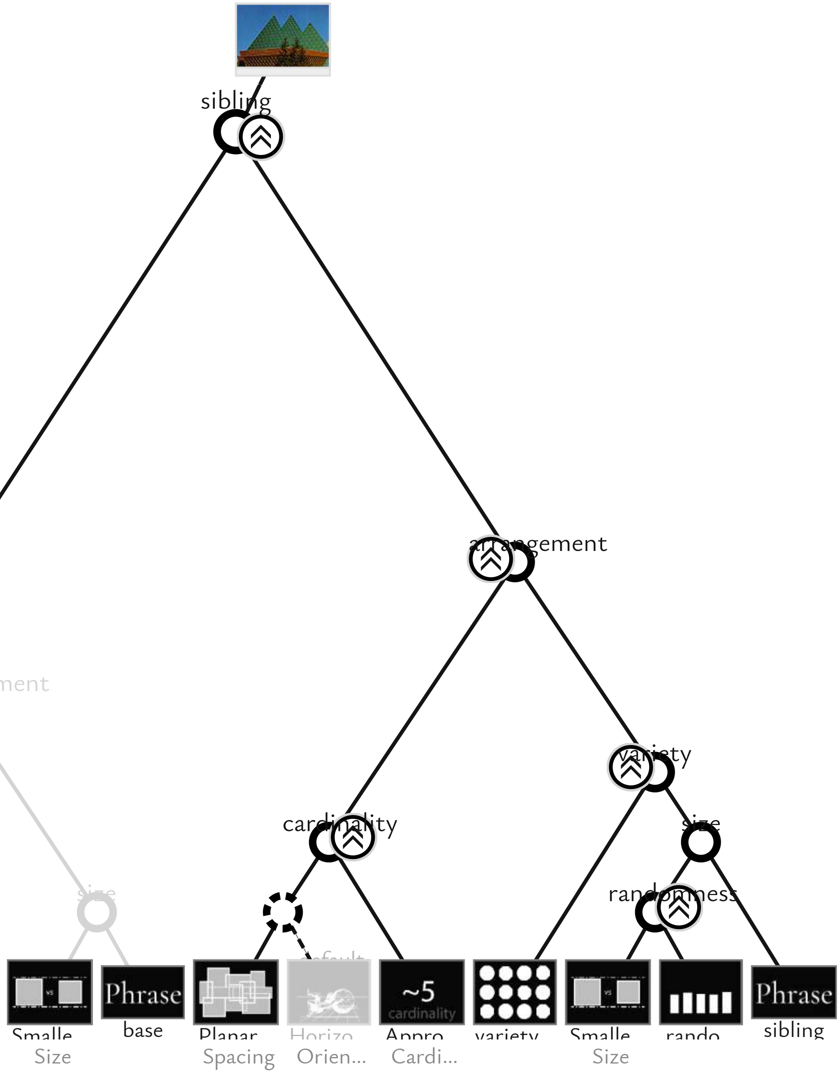
4. <Flickr_userNyclondonguy> 8015958735_16e6a7218c_b

5. <OdasanS48XreaCom> 327

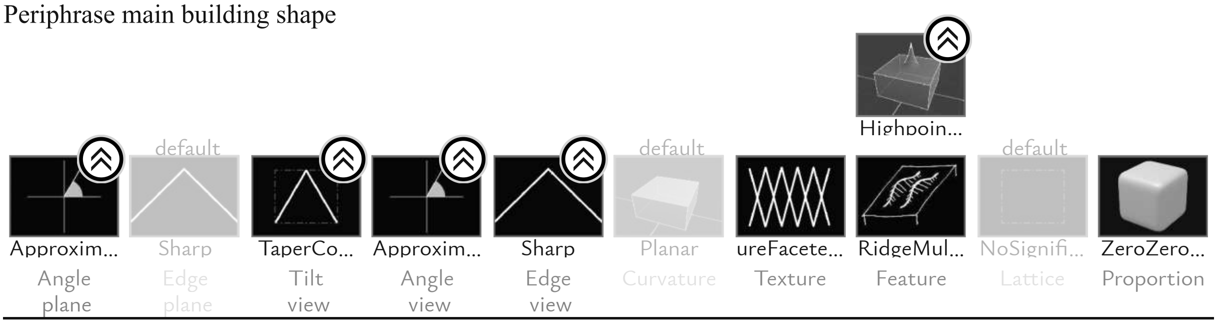
6. <PinkTentakleCom> 2844dd0b006a3d642d2f5482b47626dd

Group:	D - Multiple (Position: 7)	Year, City:	1970 Osaka
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	bg
Empirical Id:	emp-n-bg	Brief:	Bulgaria
Internal Ids:	prj3106, rep197, itm225	Full:	Bulgaria Pavilion
Tags:	expo1970/n-pav-bg	Qualified:	(see headline)

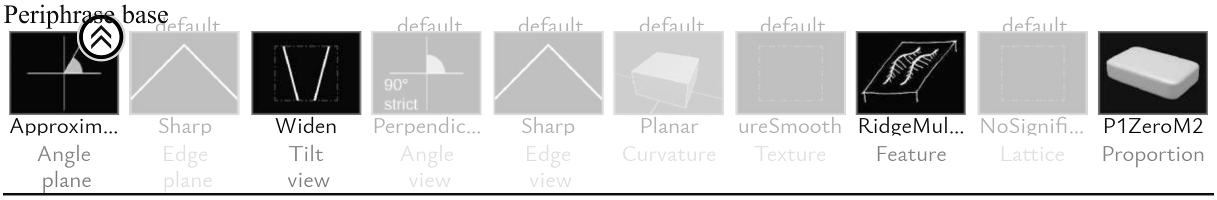
D7 - Expo 1970 Bulgaria Pavilion (Osaka)



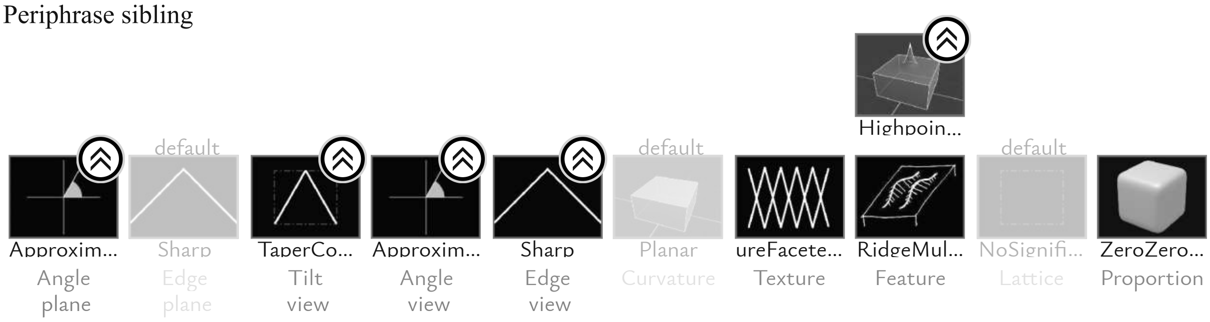
Periphrase main building shape



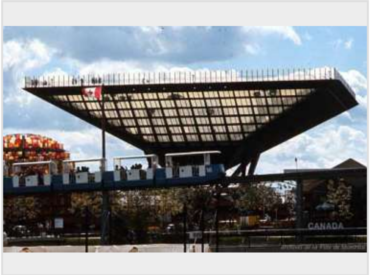
Periphrase base



Periphrase sibling



E1 - Expo 1967 Canada Host-Pavilion (Montreal)


1. <ArchivesdemontreallcaAtomOrg> VM94-EX264-012


2. <RobertLavigneCom> 03_R0648_CA

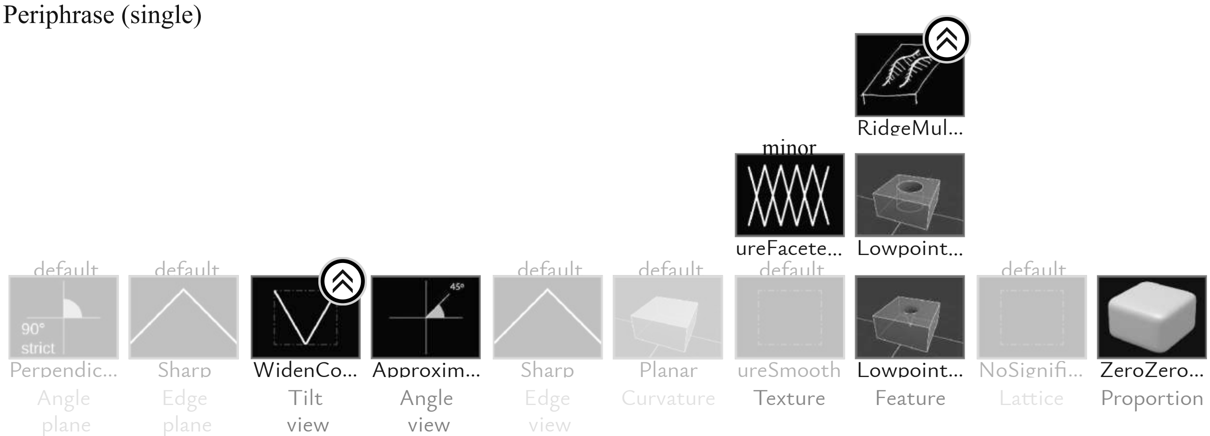

3. <Flickr_userDMorency> 2232247367_fc860653dd_o


4. <ArchivesdemontreallcaAtomOrg> VM94-B208-051


5. <GbphotodidacticalCa> Photo-Expo-67-27

Group:	E - Cantilever (Position: 1)	Year, City:	1967 Montreal
Pavilion Type:	Host Building (host)	Shortest:	h-ca
Empirical Id:	emp-host-ca	Brief:	Canada (1967)
Internal Ids:	prj2301, rep205, itm262	Full:	Canada Host-Pavilion
Tags:	expo1967/host/hn-canada-1-katimavik	Qualified:	(see headline)

Periphrase (single)



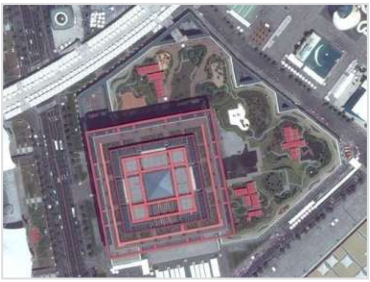
This page intentionally left blank in print layout

E2 - Expo 2010 China Host Pavilion (Shanghai)


1. <Flickr_userSteelersliu> 489 3610612_4bdb000c5a_o


2. <Expo2010ShanghaiChinaFromTheAir> 115


3. <Expo2010ShanghaiChinaFromTheAir> 114


4. <BingMaps>


5. <Flickr_userChimaybleue> 4 739748661_b595a6b843_b


6. <Flickr_userExpomuseum> 4 703260871_d06be3e75a_o


7. <Flickr_userFrankschacht> 4 999052652_c92e684c6e_b

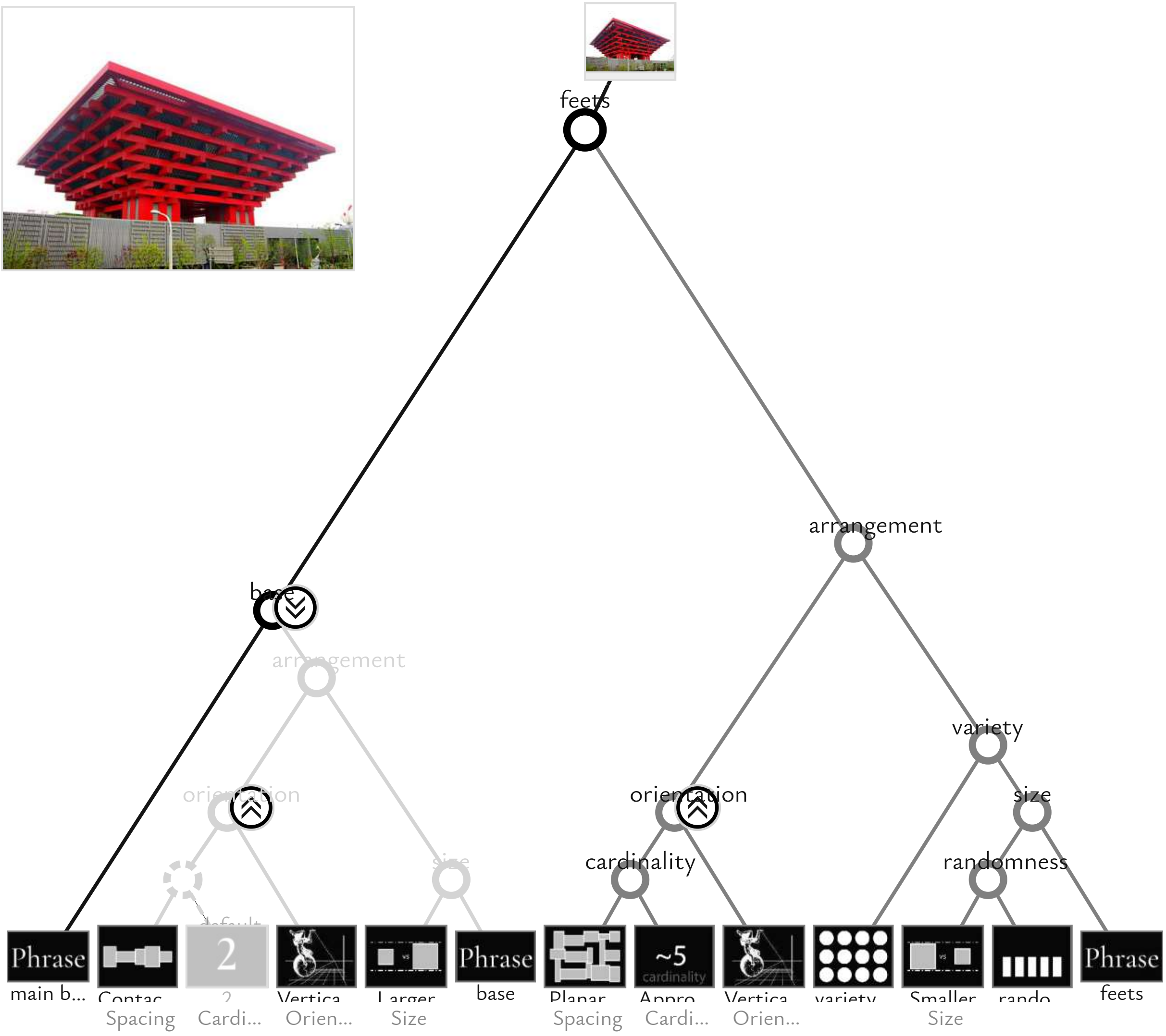

8. <Expo2010ShanghaiChinaFromTheAir> 191


9. <Flickr_userChimaybleue> 4 723333066_eb8ac8c143_b

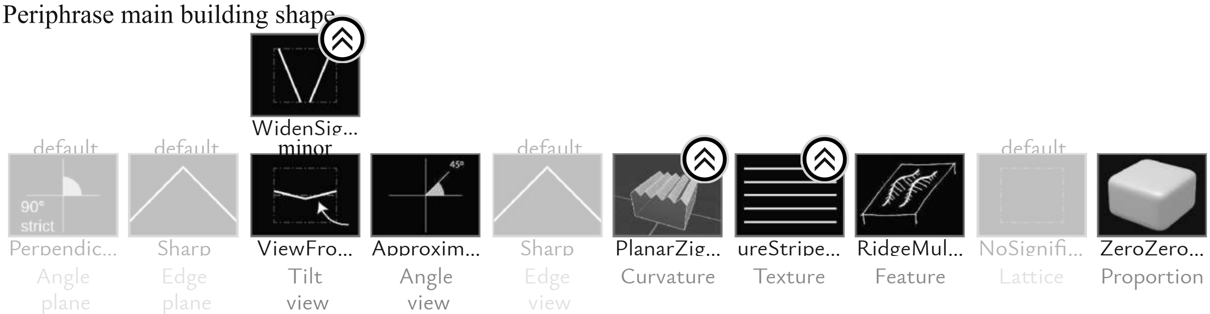
Group:	E - Cantilever (Position: 2)
Pavilion Type:	Host Building (host)
Empirical Id:	emp-host-cn
Internal Ids:	prj2001, rep206, itm235
Tags:	expo2010/host/host-pav

Year, City:	2010 Shanghai
Shortest:	h-cn
Brief:	China Host
Full:	China Host Pavilion
Qualified:	(see headline)

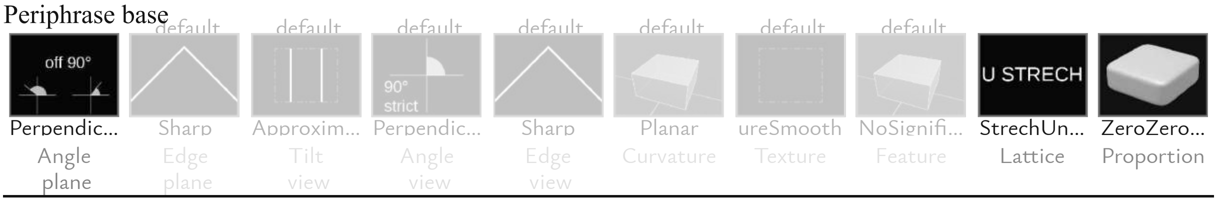
E2 - Expo 2010 China Host Pavilion (Shanghai)



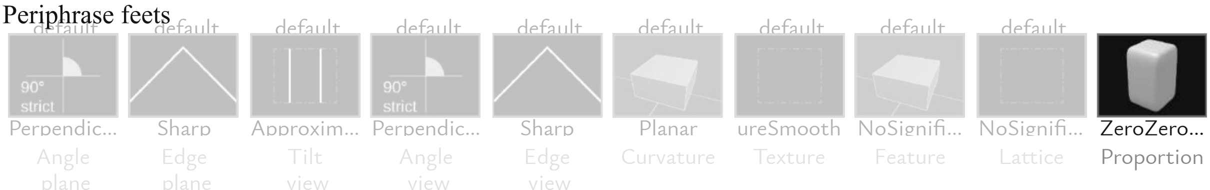
Periphrase main building shape



Periphrase base



Periphrase feets



E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)

1. <Flickr_userThePieShopsCollection> 7766428922_144da4f956_b

2. <Expo67NcfCa> kaliedscope2_expo67

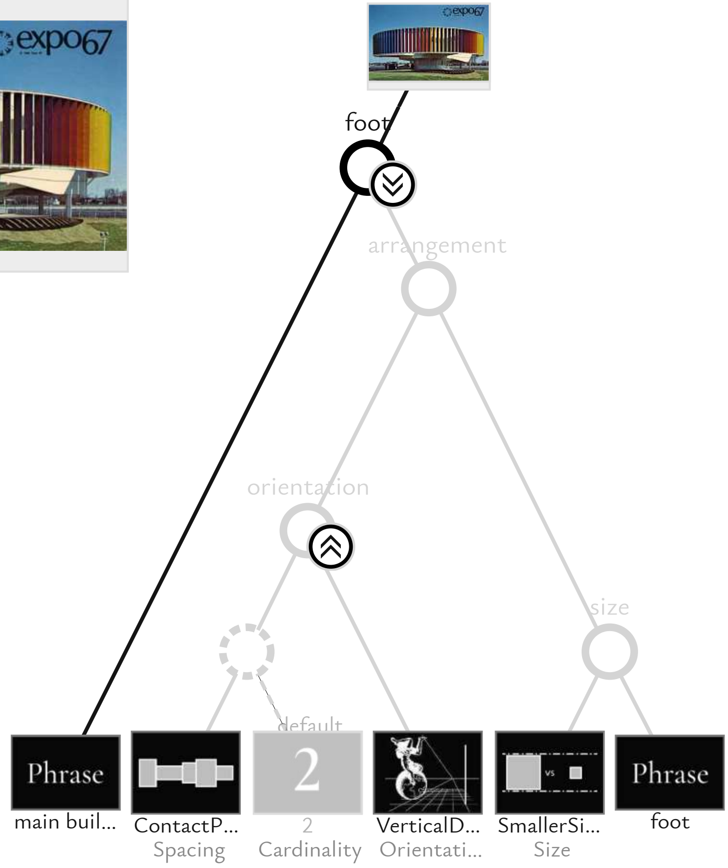
3. <CollectionscanadaGcCa> e000990846

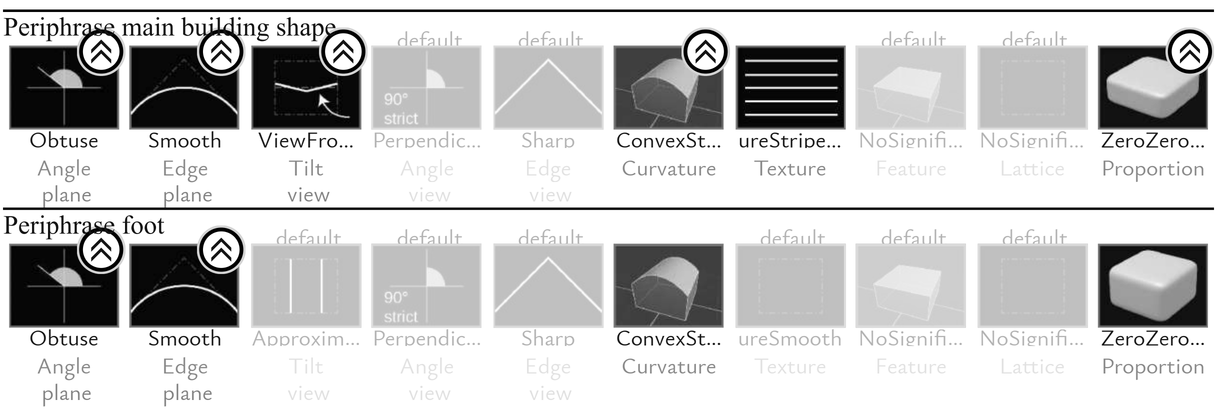
4. <ArchivesdemontreallcaAtomOrg> VM94-EX136-235

5. <Flickr_userBdutfield> 3091485744_0fa5a58cb1_o

Group:	E - Cantilever (Position: 3)	Year, City:	1967 Montreal
Pavilion Type:	Corporate Pavilion (c-pav)	Shortest:	chem
Empirical Id:	emp-c-chemical	Brief:	Kaleidoscope
Internal Ids:	prj2565, rep207, itm264	Full:	Kaleidoscope Pavilion
Tags:	expo1967/c-pav/cn-kaleidoscope	Qualified:	(see headline)

E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)





E4 - Expo 2010 Saudi Arabia Pavilion (Shanghai)

1. <Expo2010ShanghaiChinaFromTheAir> expo0015

2. <Flickr_userMeiguoxing> 4562528348_262feed030_z

3. <BingMaps>

4. <Flickr_userGavinbloys> 5203599583_06f64ddfdb_o

5. <Flickr_userWojtekgurak> 5443525616_612f45f18f_o

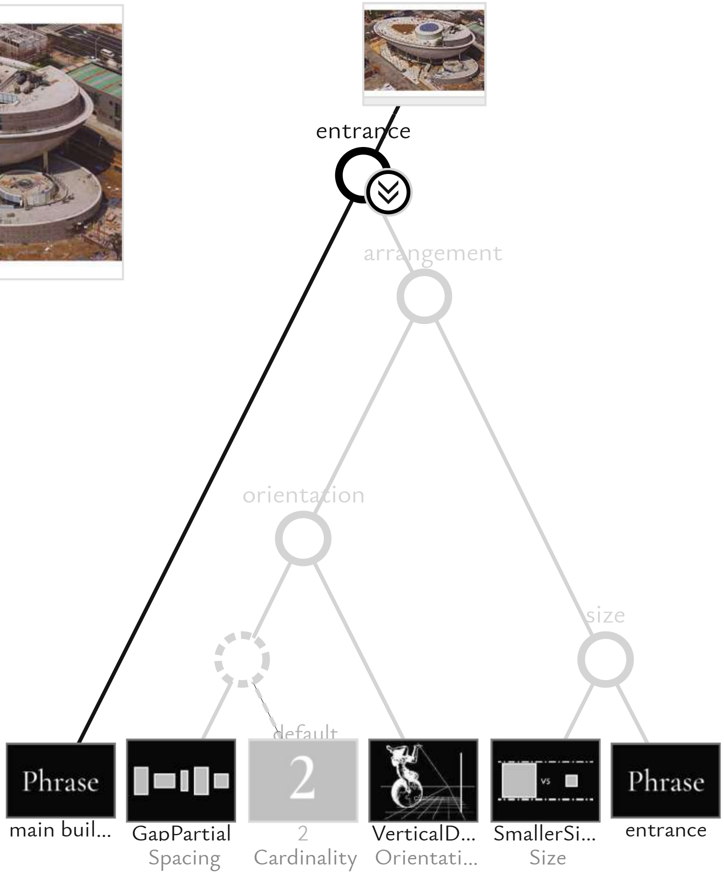
6. <Flickr_userWentaoYin12> 5567872559_12e9c145e8_o

7. <PJ> 1040635

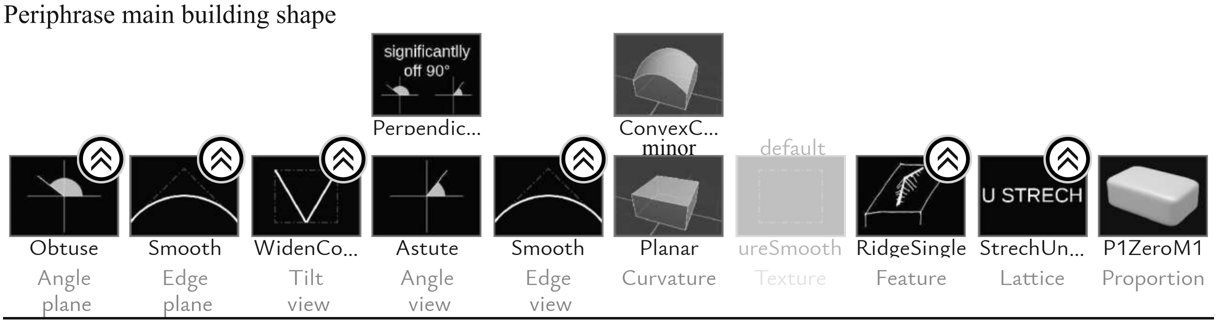
8. <Flickr_userExpomuseum> 4674353294_798b6a0b6f_o

Group:	E - Cantilever (Position: 4)	Year, City:	2010 Shanghai
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	sa
Empirical Id:	emp-n-sa	Brief:	Saudi Arabia
Internal Ids:	prj2164, rep210, itm236	Full:	Saudi Arabia Pavilion
Tags:	expo2010/n-pav-sa/nn-saudiArabia	Qualified:	(see headline)

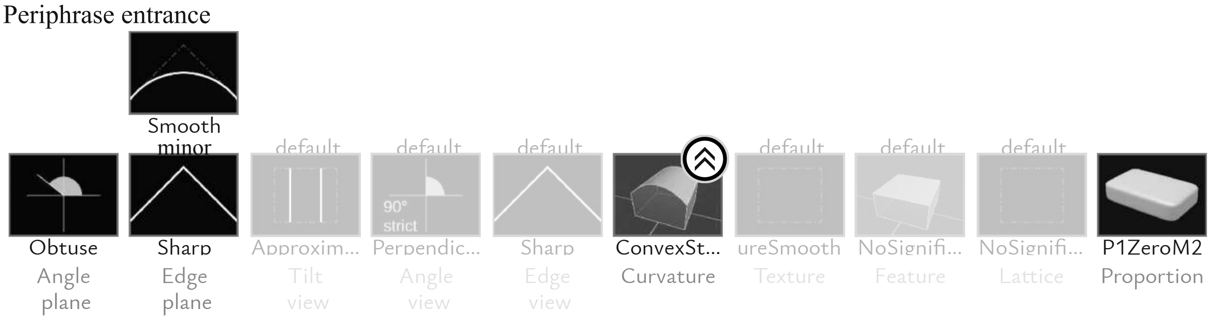
E4 - Expo 2010 Saudi Arabia Pavilion (Shanghai)



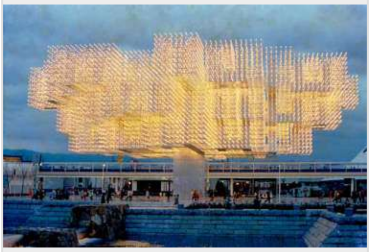
Periphrase main building shape



Periphrase entrance

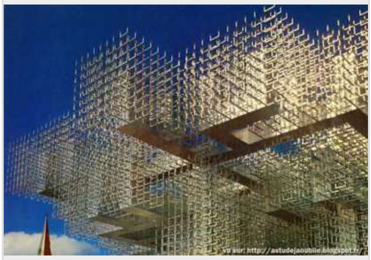


E5 - Expo 1970 Switzerland Pavilion (Osaka)

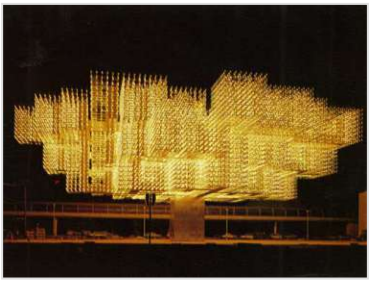


1. <Flickr_userMLouis> 1182780849_4f3eaf9d63_o

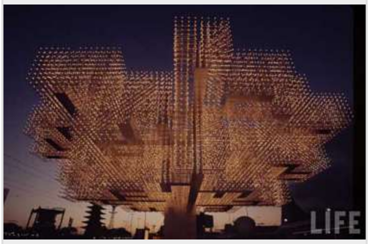
2. <Magnum_byFerdinandoScianna> PAR327597



3. <AstudejaoublieBlogspotFr_byFukudaCard> japon10



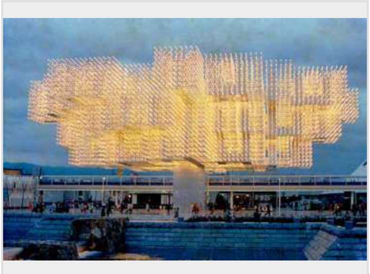
4. <Flickr_userKOota> 5799145518_a36c64772c_o

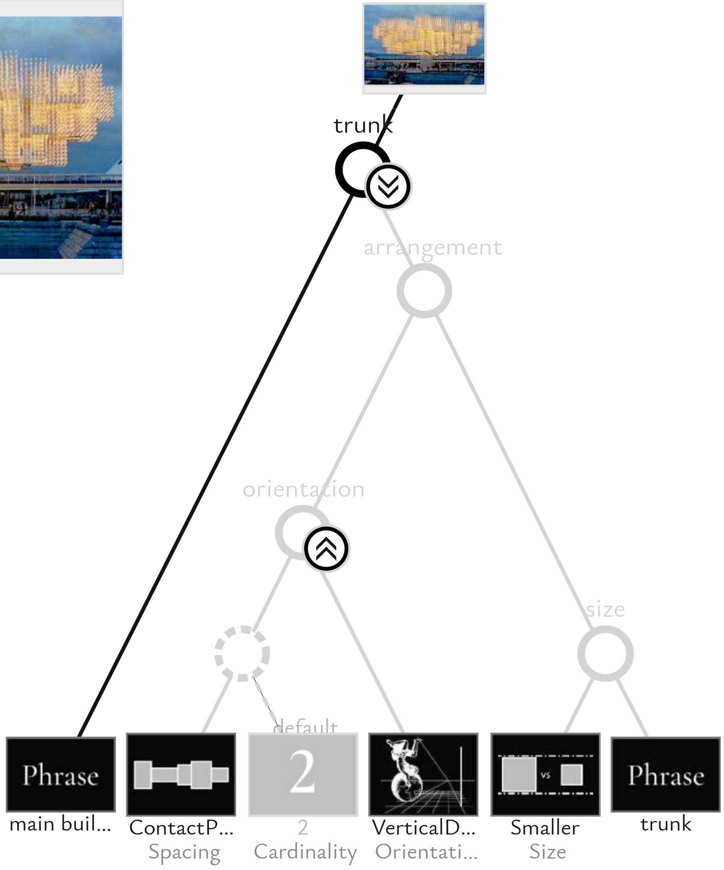


5. <Life_byCarlMydans> 01

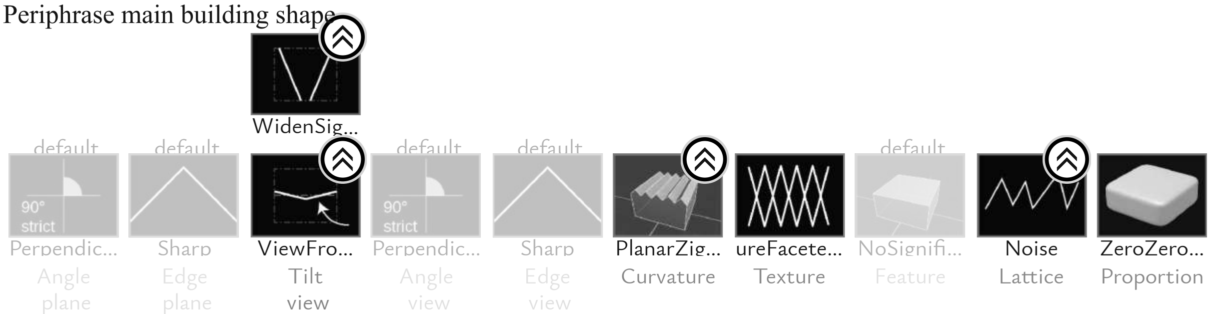
Group:	E - Cantilever (Position: 5)	Year, City:	1970 Osaka
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	ch
Empirical Id:	emp-n-ch	Brief:	Switzerland
Internal Ids:	prj3109, rep209, itm218	Full:	Switzerland Pavilion
Tags:	expo1970/n-pav-ch	Qualified:	(see headline)

E5 - Expo 1970 Switzerland Pavilion (Osaka)

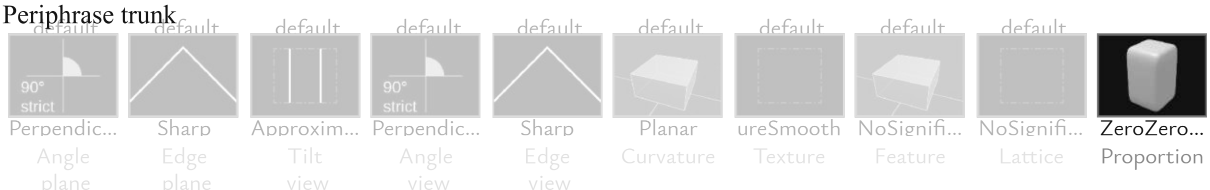




Periphrase main building shape



Periphrase trunk



E6 - Expo 1967 Quebec Region Pavilion (Montreal)

1. <ArchivesdemontrealIcaAtomOrg> VM94-EX265-127

2. <Flickr_userErezUploadedByMagstb67> 2717451653_250796d831_o

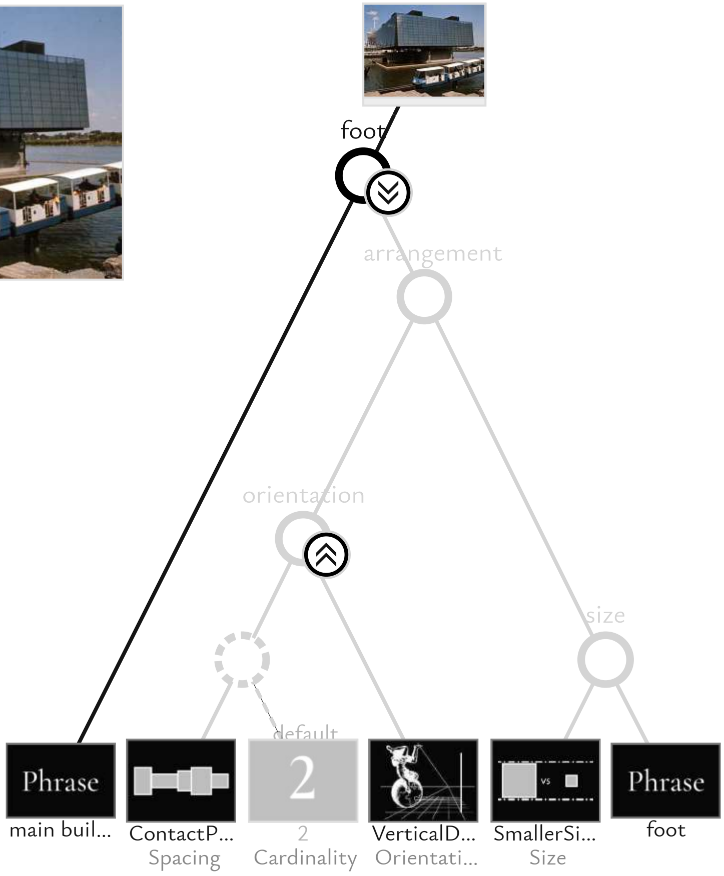
3. <ArchivesdemontrealIcaAtomOrg> VM94-EX96-031

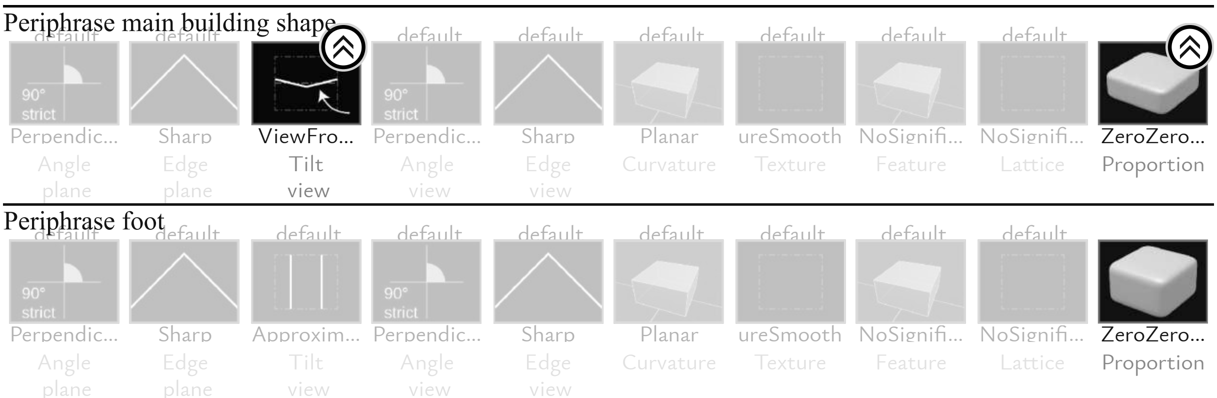
4. <ArchivesdemontrealIcaAtomOrg> VM94-B253-015

5. <CollectionscanadaGcCa> e000990853

Group:	E - Cantilever (Position: 6)	Year, City:	1967 Montreal
Pavilion Type:	Region Pavilion (r-pav)	Shortest:	que
Empirical Id:	emp-r-quebec	Brief:	Quebec
Internal Ids:	prj2355, rep208, itm207	Full:	Quebec Region Pavilion
Tags:	expo1967/r-pav/rn-quebec	Qualified:	(see headline)

E6 - Expo 1967 Quebec Region Pavilion (Montreal)





E7 - Expo 2010 South Korea Pavilion (Shanghai)

1. <Flickr_userExpomuseum> 4781946933_842870d856_o

2. <PJ> 1040627

3. <Flickr_userExpomuseum> 4795272684_eb6f82a1b3_o

4. <Flickr_userExpomuseum> 4795270648_d0219a0b0e_o

5. <StatesOfArchitectures_by NicLehoux> 7

6. <Flickr_userSteelersliu> 4893013587_04e7dcec93_o

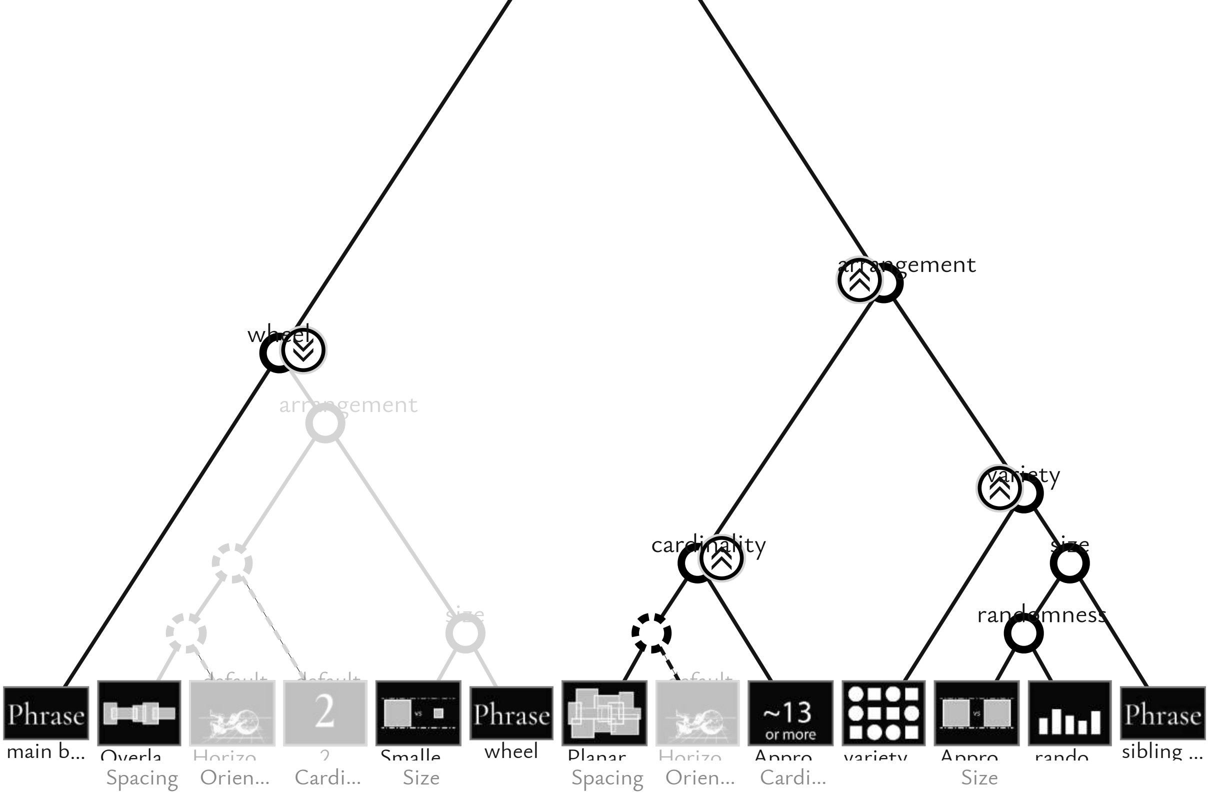
7. <Flickr_userKimon> 4680633725_e87d552b50_o

8. <BingMaps>

9. <StatesOfArchitectures_by NicLehoux> 4

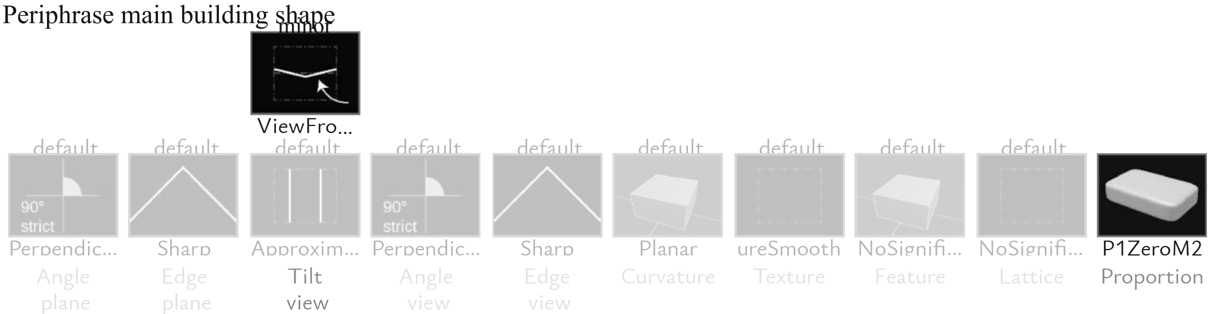
Group:	E - Cantilever (Position: 7)	Year, City:	2010 Shanghai
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	kr
Empirical Id:	emp-n-kr	Brief:	South Korea
Internal Ids:	prj2137, rep211, itm192	Full:	South Korea Pavilion
Tags:	expo2010/n-pav-kr/nn-southKorea	Qualified:	(see headline)

E7 - Expo 2010 South Korea Pavilion (Shanghai)

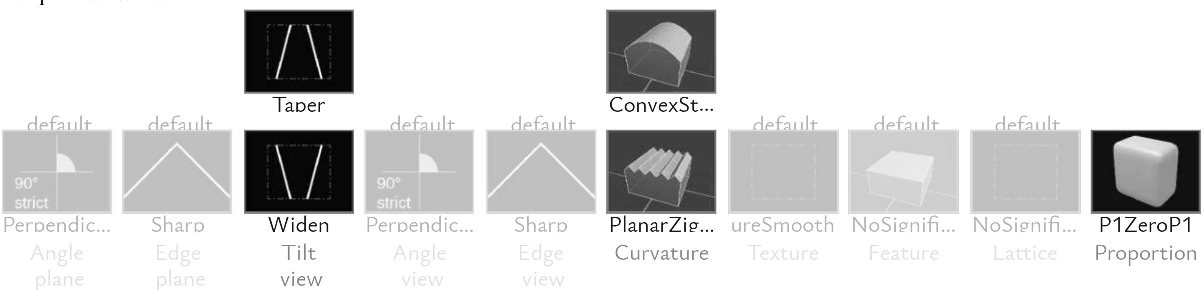


E7 - Expo 2010 South Korea Pavilion (Shanghai)

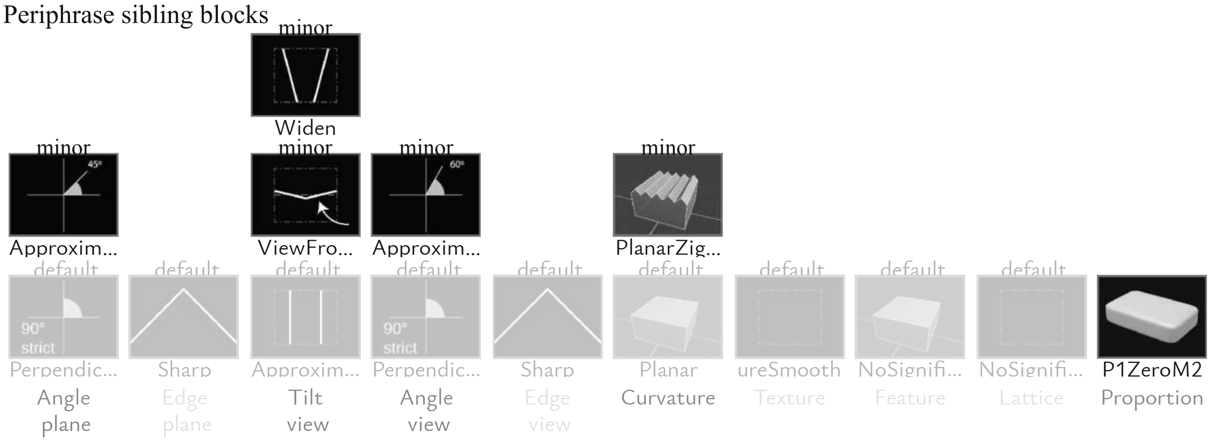
Periphrase main building shape



Periphrase wheel



Periphrase sibling blocks



This page intentionally left blank in print layout

F1 - Expo 1970 Fuji Corporate Pavilion (Osaka)


1. <PoltrackNet_byJohnPoltrack> FujiGroupPavilion-20131103


2. <UNSW_LSRU_Archive> JP-004_0002


3. <Flickr_userKOota> 5799143262_05c3120729_o


4. <UNSW_LSRU_Archive> SY-022_0011

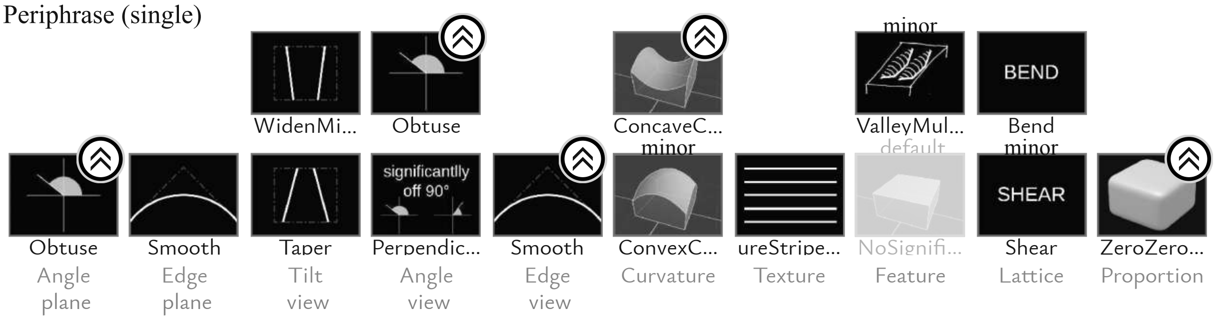

5. <KawaguchiEngineers> espana-1020982


6. <Sonynaviblogsonetnejp> dsc03495


7. <KawaguchiEngineers> espana-1020980

Group:	F - Blob (Position: 1)	Year, City:	1970 Osaka
Pavilion Type:	Corporate Pavilion (c-pav)	Shortest:	fuji
Empirical Id:	emp-c-fuji	Brief:	Fuji
Internal Ids:	prj3244, rep212, itm215	Full:	Fuji Corporate Pavilion
Tags:	expo1970/c-pav/cn-fuji	Qualified:	(see headline)

Periphrase (single)



F2 - Expo 2010 Japan Pavilion (Shanghai)


1. <Expo2010ShanghaiChinaFromTheAir> expo0001


2. <GoogleMaps>


3. <Panoramio_user557748(jsduo44)> 38676560


4. <Flickr_userChazhutton> 4554148507_ebc57665f4_o


5. <Flickr_userExpomuseum> 4795247452_786d06ec26_o

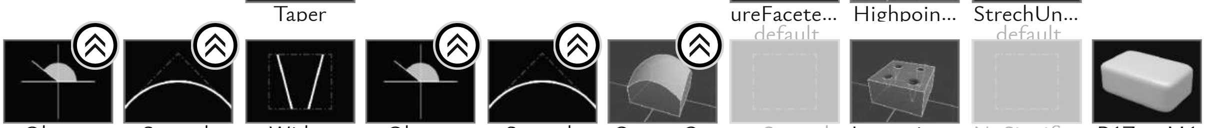

6. <11tecomBlog163Com_byAFP> Shanghai_Expo--7--600x400


7. <WsjCom> OB-HQ504_0223ex_H_20100223040326

Group:	F - Blob (Position: 2)	Year, City:	2010 Shanghai
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	jp10
Empirical Id:	emp-n-jp10	Brief:	Japan (2010)
Internal Ids:	prj2134, rep214, itm245	Full:	Japan Pavilion (2010)
Tags:	expo2010/n-pav-jp/nn-japan	Qualified:	(see headline)

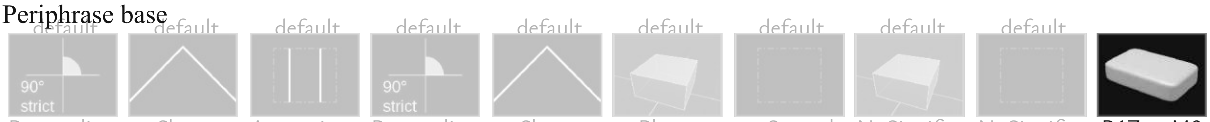
Periphrase main building shape

Taper | ureFacete... | Highpoin... | StrechUn...



Obtuse Angle plane | Smooth Edge plane | Widen Tilt view | Obtuse Angle view | Smooth Edge view | ConvexC... Curvature | ureSmooth Texture | Lowpoint... Feature | NoSignifi... Lattice | P1ZeroM1 Proportion

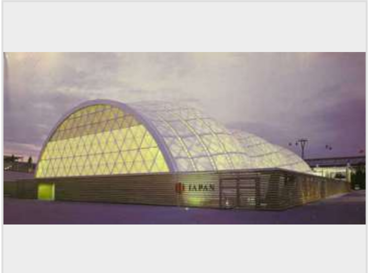
Periphrase base



Perpendic... Angle plane | Sharp Edge plane | Approxim... Tilt view | Perpendic... Angle view | Sharp Edge view | Planar Curvature | ureSmooth Texture | NoSignifi... Feature | NoSignifi... Lattice | P1ZeroM2 Proportion

F3 - Expo 2000 Japan Pavilion (Hannover)

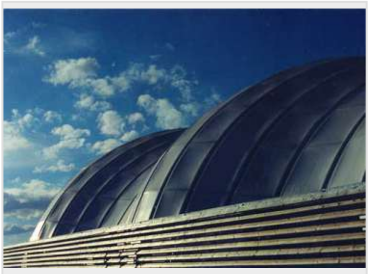
1. <Wikipedia_byJensBludau> Expo2000Japan



2. <ArchitectureExpo2000Hannover> IMG_1066

3. <Flickr_userExpomuseum> 67823628_1f52ce12c9_o

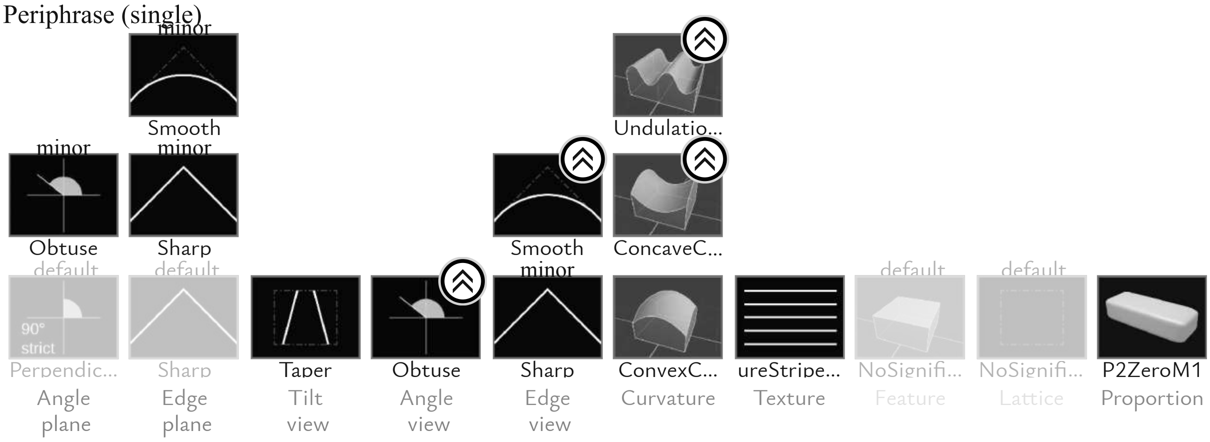
4. <Expo2000De> 100142344



5. <Flickr_userCesarCorona> 2394266846_03b3bd3f39_o

Group:	F - Blob (Position: 3)	Year, City:	2000 Hannover
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	jp00
Empirical Id:	emp-n-jp00	Brief:	Japan (2000)
Internal Ids:	prj3422, rep213, itm188	Full:	Japan Pavilion (2000)
Tags:	expo2000/n-pav-jp	Qualified:	(see headline)

Periphrase (single)



F4 - Expo 2000 Hope Theme Pavilion (Hannover)


1. <Panoramio_user775448-brickl> 26719555


2. <Panoramio_user775448-brickl> 32944272


3. <Panoramio_user775448-brickl> 30588314


4. <Panoramio_user775448-brickl> 32943293

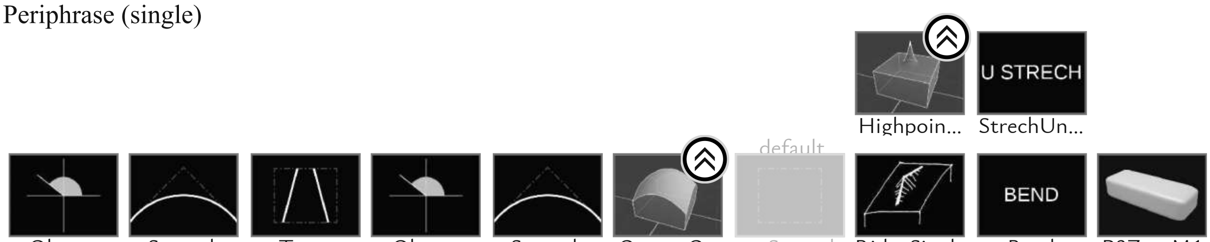

5. <GoogleEarth> 2013-walfisch


6. <Wikipedia_byMisburg3014> Hannover_Expo-Wal-2009


7. <Flickr_userMikeBulter> 14438234013_cb01a4ce20_o

Group:	F - Blob (Position: 4)	Year, City:	2000 Hannover
Pavilion Type:	Theme Pavilion (t-pav)	Shortest:	hope
Empirical Id:	emp-t-hope	Brief:	Pavilion Of Hope
Internal Ids:	prj3332, rep218, itm182	Full:	Hope Theme Pavilion
Tags:	expo2000/t-pav/tn-pavilionOfHope	Qualified:	(see headline)

Periphrase (single)



F5 - Expo 2010 Aviation Pavilion (Shanghai)


1. <PJ> 1040420


2. <PJ> 1040430


3. <Expo2010ShanghaiChinaFromTheAir> expo0047b


4. <PJ> 1040423


5. <Panoramio_user2485865_(ThomasPrinz)> 41559885


6. <Flickr_userPicturenarrative> 4984756680_59614f9e58_b

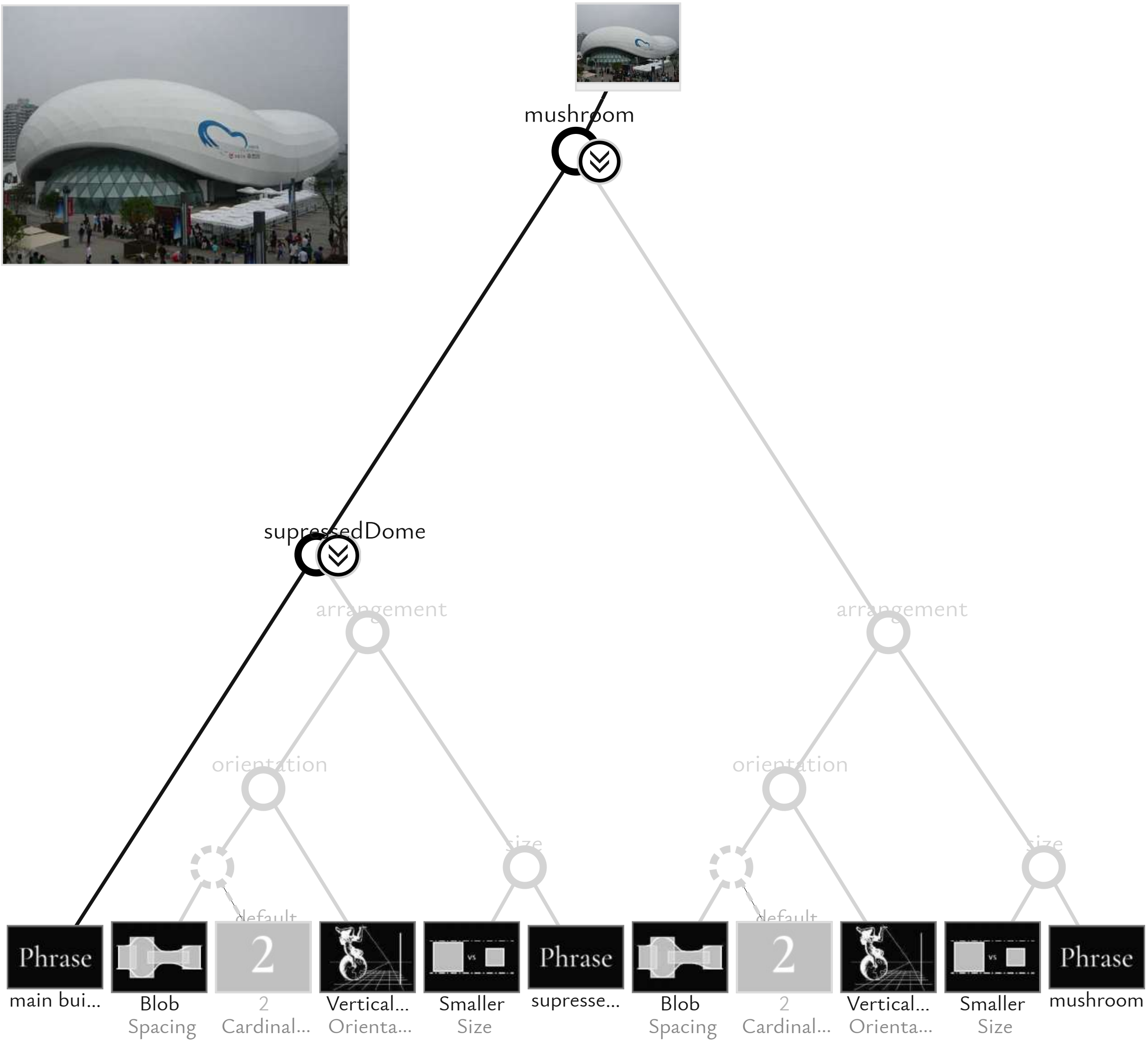

7. <PJ> 1040411


8. <BingMaps>

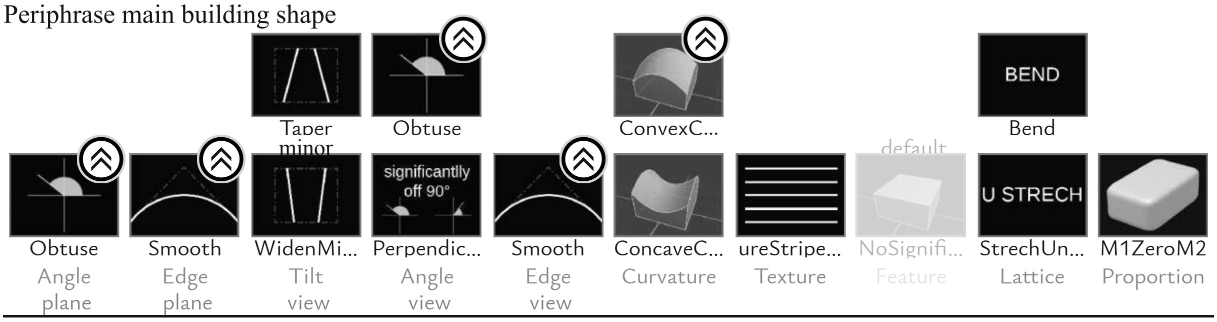

9. <Flickr_userBolorocco> 5195541374_0217d676bb_o

Group:	F - Blob (Position: 5)	Year, City:	2010 Shanghai
Pavilion Type:	Corporate Pavilion (c-pav)	Shortest:	avi
Empirical Id:	emp-c-aviation	Brief:	Aviation
Internal Ids:	prj2262, rep217, itm204	Full:	Aviation Pavilion
Tags:	expo2010/c-pav/cn-aviation	Qualified:	(see headline)

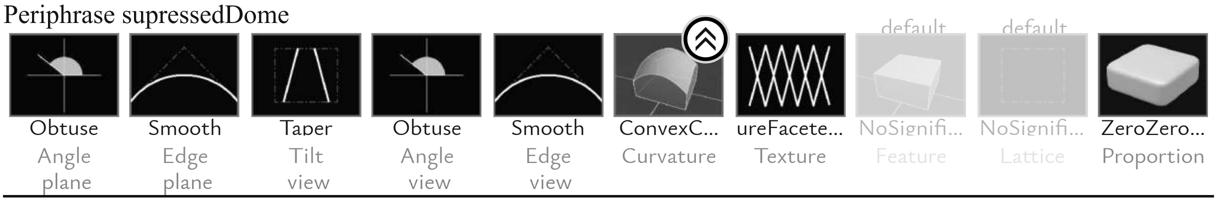
F5 - Expo 2010 Aviation Pavilion (Shanghai)



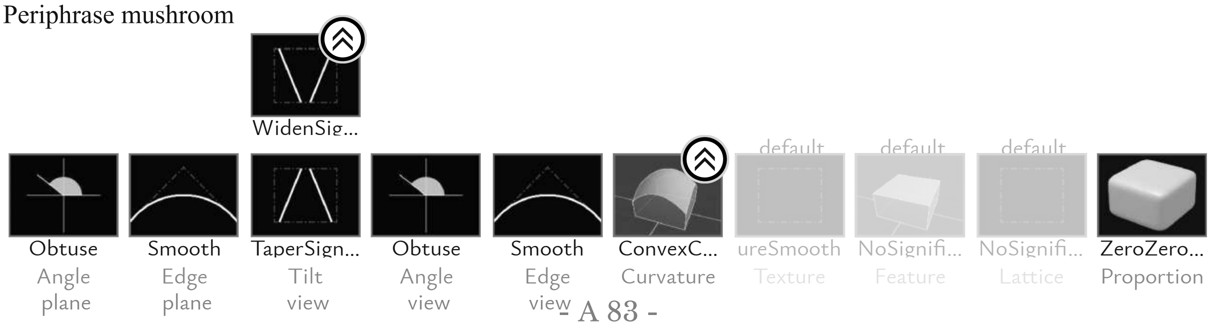
Periphrase main building shape



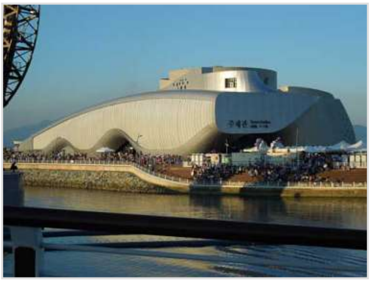
Periphrase supressedDome



Periphrase mushroom

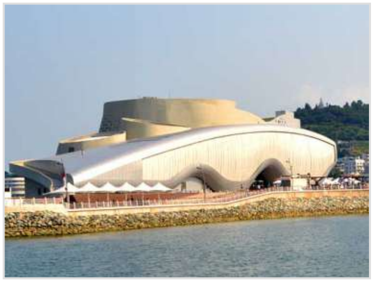


F6 - Expo 2012 Ocean Coast Pavilion (Yeosu)



1. <Panoramio_userPlumgarden_(54048)> 76578551

2. <Panoramio_user(utf8)_(3705168)> 76764437



3. <Panoramio_user(utf8)_(3705168)> 76721960

4. <Flickr_userExpomuseum> 7860007940_0e17823e35_o

5. <GoogleMaps>

6. <Flickr_userSSchleicher> 7341289416_2553f4ae89_b

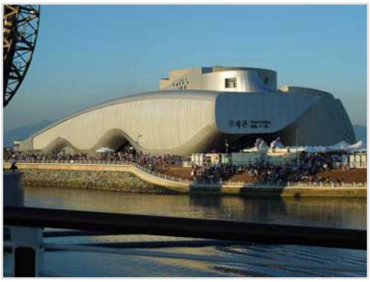
7. <Flickr_userSSchleicher> 7156086889_0192f40c8a_b

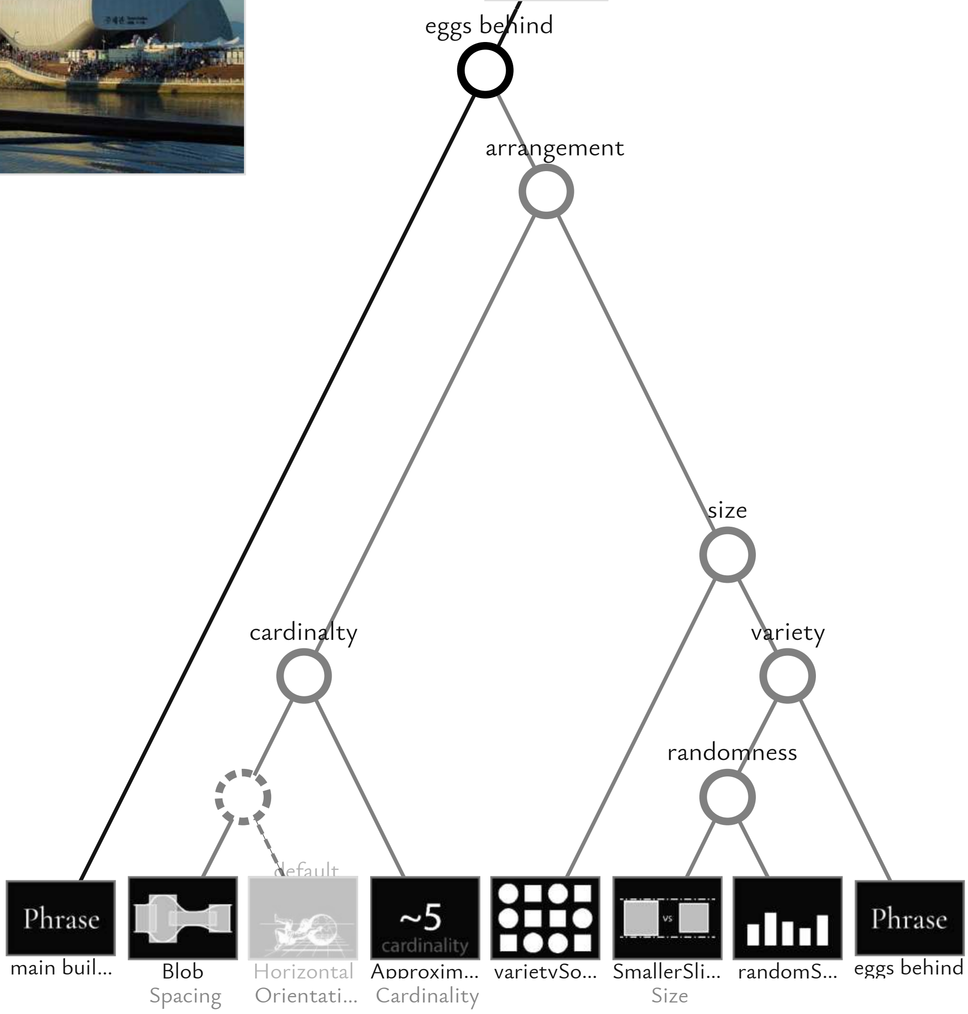
8. <Flickr_userCesarCorona> 8829588962_8e06d7e9b9_o

9. <Panoramio_user(utf8)_(3705168)> 76670467

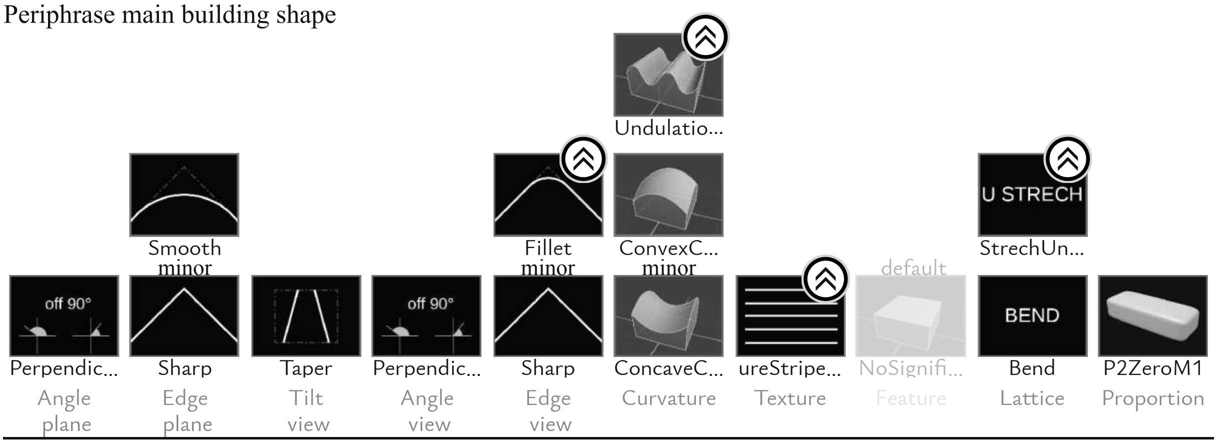
Group:	F - Blob (Position: 6)	Year, City:	2012 Yeosu
Pavilion Type:	Theme Pavilion (t-pav)	Shortest:	oce
Empirical Id:	emp-t-ocean	Brief:	Ocean Coast
Internal Ids:	prj2635, rep216, itm187	Full:	Ocean Coast Pavilion
Tags:	expo2012/t-pav/tn-oceanCoast	Qualified:	(see headline)

F6 - Expo 2012 Ocean Coast Pavilion (Yeosu)

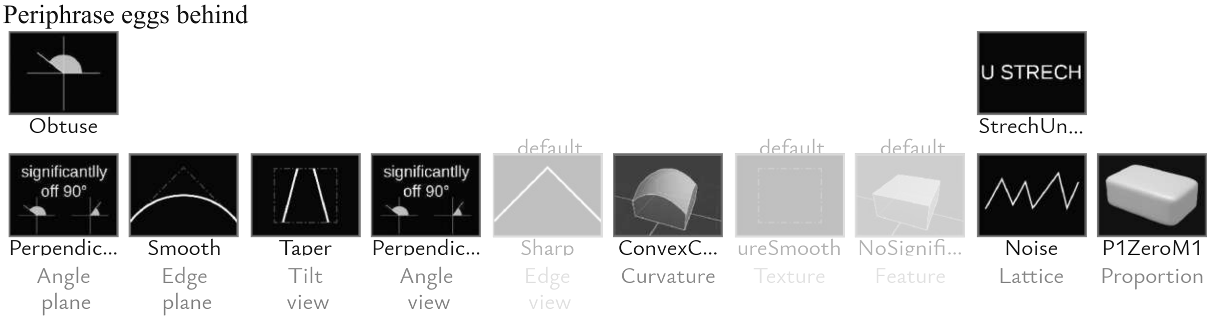




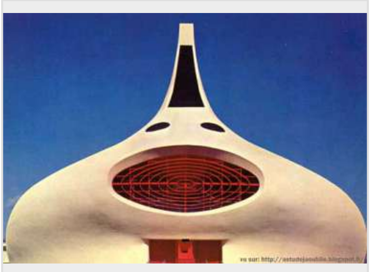
Periphrase main building shape



Periphrase eggs behind



F7 - Expo 1970 Gas Corporate Pavilion (Osaka)



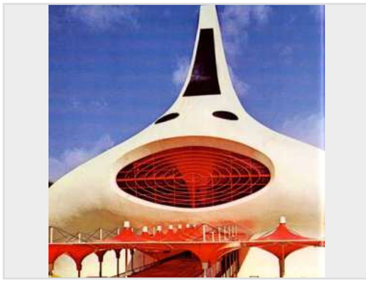
1. <AstudejaoublieBlogspotFr_byFukudaCard> japon18

2. <Flickr_userLaurentBaudoux> 304876264_d01ed04101_o

3. <Flickr_userNyclondonguy> 8012552953_53f1672980_k

4. <Sonynaviblogsonetnejp> dsc03496-957f4

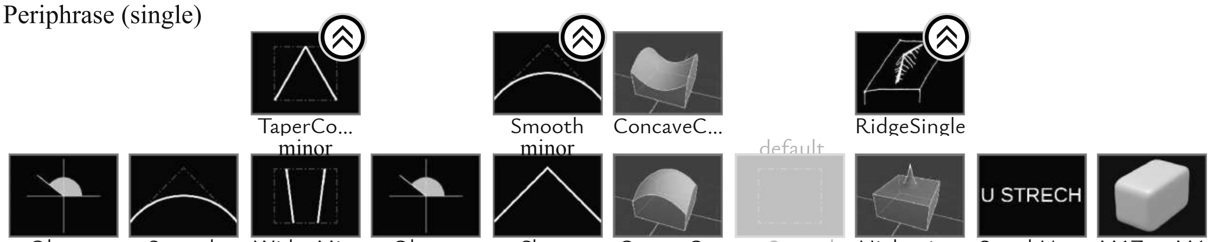
5. <Flickr_userKOota> 5798599771_b62b240285_o



6. <Weltausstellungen>

Group:	F - Blob (Position: 7)	Year, City:	1970 Osaka
Pavilion Type:	Corporate Pavilion (c-pav)	Shortest:	gas
Empirical Id:	emp-c-gas	Brief:	Gas
Internal Ids:	prj3246, rep215, itm226	Full:	Gas Corporate Pavilion
Tags:	expo1970/c-pav/cn-gas	Qualified:	(see headline)

Periphrase (single)



Obtuse Angle plane | Smooth Edge plane | WidenMi... Tilt view | Obtuse Angle view | Sharp Edge view | ConvexC... Curvature | ureSmooth Texture | Highpoin... Feature | StrechUn... Lattice | M1ZeroM1 Proportion

This page intentionally left blank in print layout

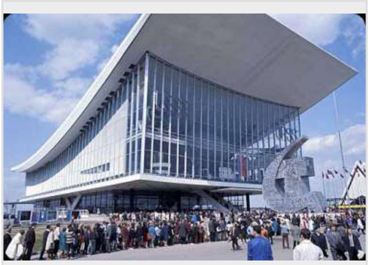
G1 - Expo 1967 Soviet Union Pavilion (Montreal)

1. <Flickr_userThePieShopsCollection> 5560908841_0cf4e19fa9_b

2. <ArchivesdemontrealIcaAtomOrg> VM94-EX48-001

3. <CollectionscanadaGcCa> e000990855

4. <Flickr_userThePieShopsCollection> 6546656985_002ffa7fc1_b

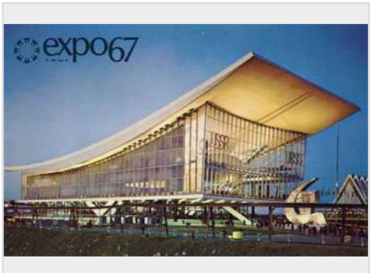


5. <CollectionscanadaGcCa> e000990955

6. <Flickr_userErezUploadedByMagstb67> 2717477145_f6c664f65c_o

7. <Flickr_userPetespix75> nr01

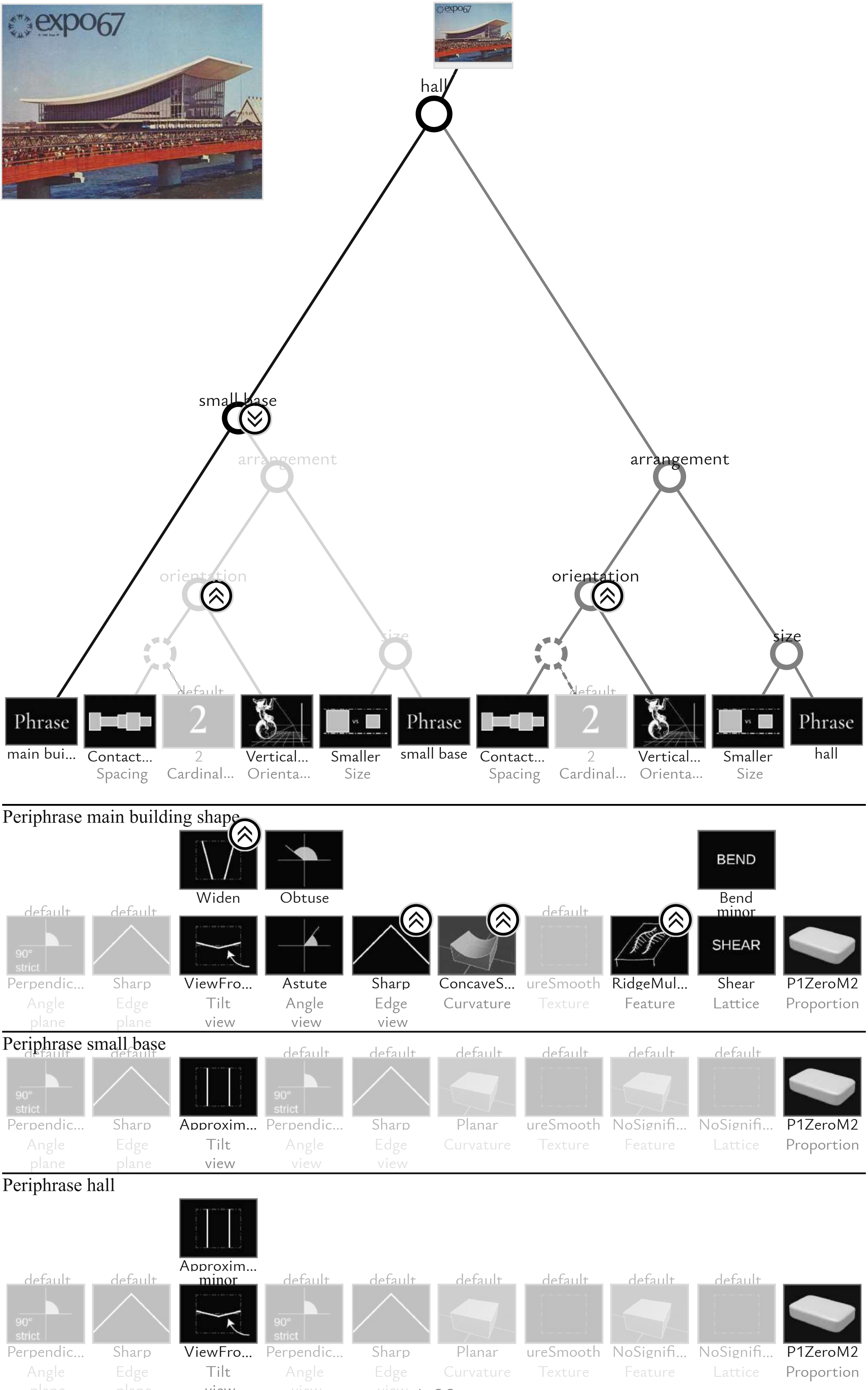
8. <Flickr_userMagstb67> 2597978957_43739f7ddc_o



9. <AlamedainfoCom> Soviet_Union_Pavilion_Expo_67_Montreal_Canada_EX203

Group:	G - Concave (Position: 1)	Year, City:	1967 Montreal
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	su67
Empirical Id:	emp-n-su67	Brief:	Soviet Union (1967)
Internal Ids:	prj2427, rep219, itm210	Full:	Soviet Union Pavilion (1967)
Tags:	expo1967/n-pav-su/nn-sovietUnion	Qualified:	(see headline)

G1 - Expo 1967 Soviet Union Pavilion (Montreal)



G2 - Expo 2012 Hyundai Corporate Pavilion (Yeosu)

1. <Flickr_userExpomuseum> 7836263826_7724ac7827_o

2. <Flickr_userCesarCorona> 7167769559_6681accb96_o

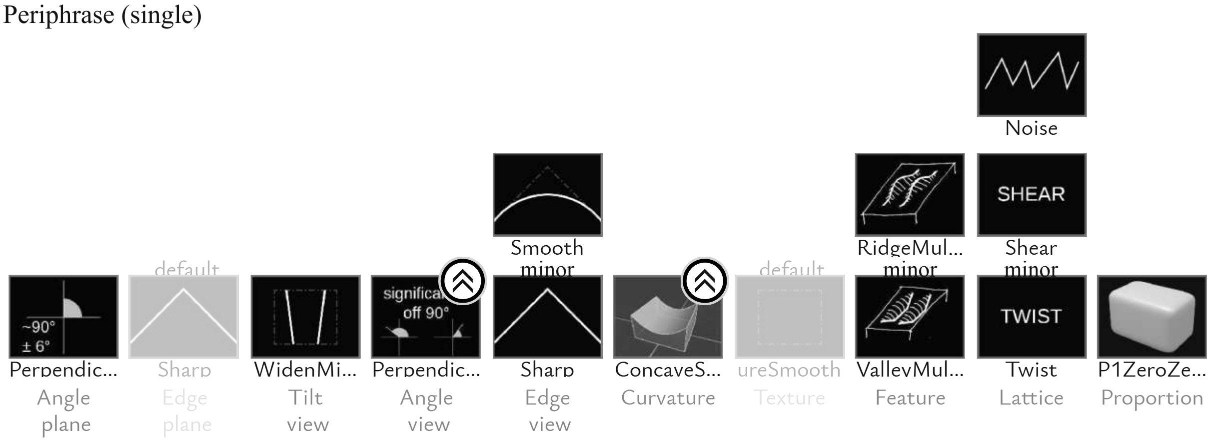
3. <Flickr_userHtglss> 7494162614_a7acbcaa23_o

4. <Panoramio_userPlumgarden_(54048)> 76697076

5. <Panoramio_userPlumgarden_(54048)> 76696978

Group:	G - Concave (Position: 2)	Year, City:	2012 Yeosu
Pavilion Type:	Corporate Pavilion (c-pav)	Shortest:	hyu
Empirical Id:	emp-c-hyundai	Brief:	Hyundai
Internal Ids:	prj2653, rep220, itm220	Full:	Hyundai Corporate Pavilion
Tags:	expo2012/c-pav/cn-hyundai	Qualified:	(see headline)

Periphrase (single)

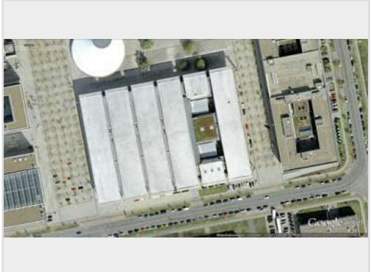


This page intentionally left blank in print layout

G3 - Expo 2000 Germany Host Pavilion (Hannover)


1. <Wikipedia_byAxelHH> Deutscher_Pavillon_2011


2. <ArchitectureExpo2000Hannover> IMG_1130b


3. <GoogleEarth> y2006_host-pav


4. <Flickr_userExpomuseum> 67848771_7d7c696843_o


5. <Panoramio_user775448-brickl> 25992918


6. <Panoramio_user775448-brickl> 25993084

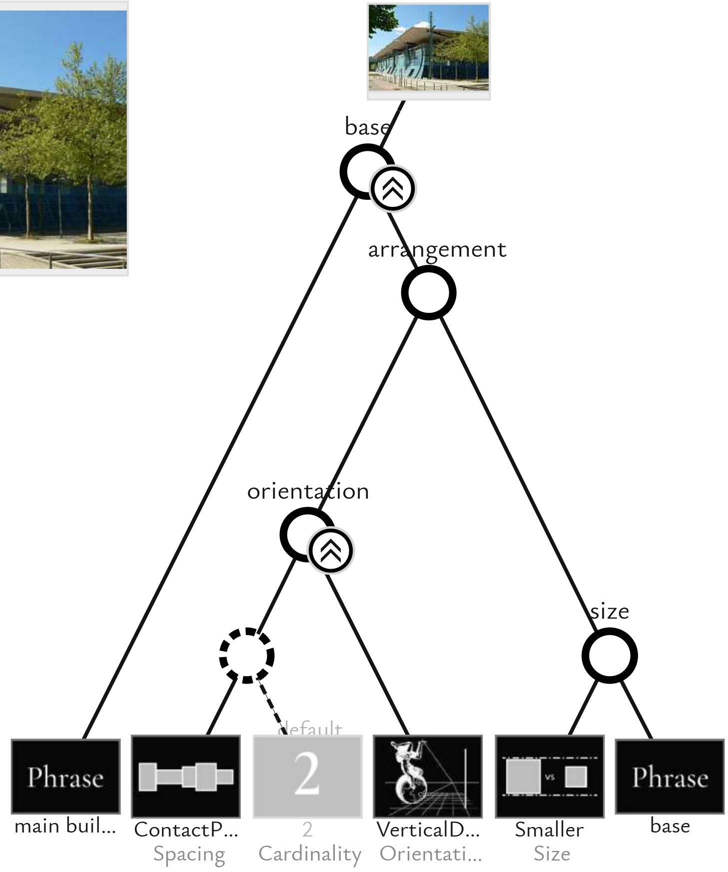

7. <Panoramio_user775448-brickl> 32939643


8. <Panoramio_user775448-brickl> 30667395

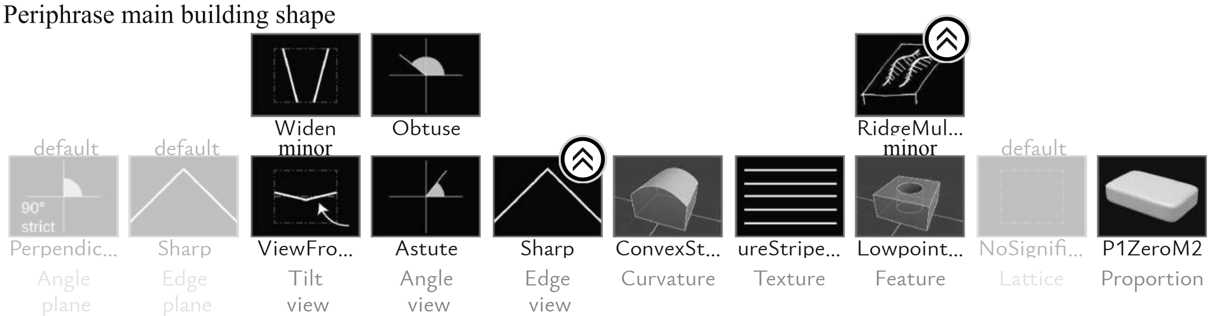

9. <Panoramio_user775448-brickl> 32937796

Group:	G - Concave (Position: 3)	Year, City:	2000 Hannover
Pavilion Type:	Host Building (host)	Shortest:	h-de
Empirical Id:	emp-host-de	Brief:	Germany Host
Internal Ids:	prj3301, rep221, itm190	Full:	Germany Host Pavilion
Tags:	expo2000/host/hn-germany	Qualified:	(see headline)

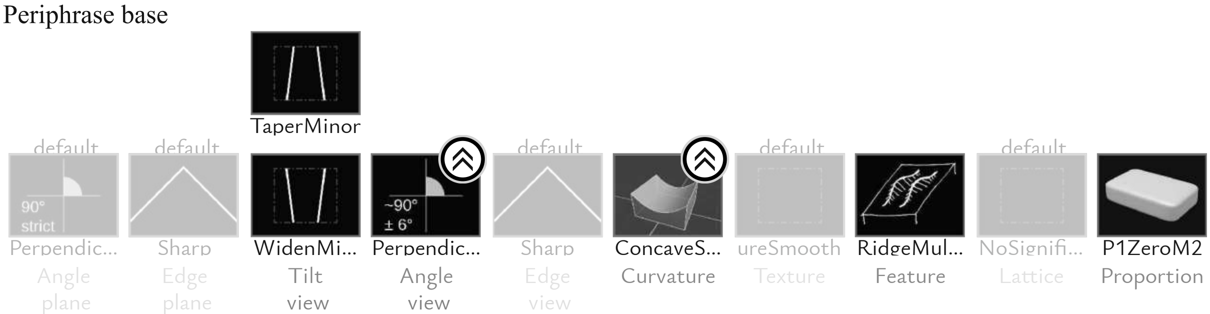
G3 - Expo 2000 Germany Host Pavilion (Hannover)



Periphrase main building shape



Periphrase base



G4 - Expo 2010 Brazil Pavilion (Shanghai)

1. <Flickr_userFrankschacht> 4629685266_3a1c0274ee_b

2. <Flickr_userKimon> 4693995743_9612865ef6_o

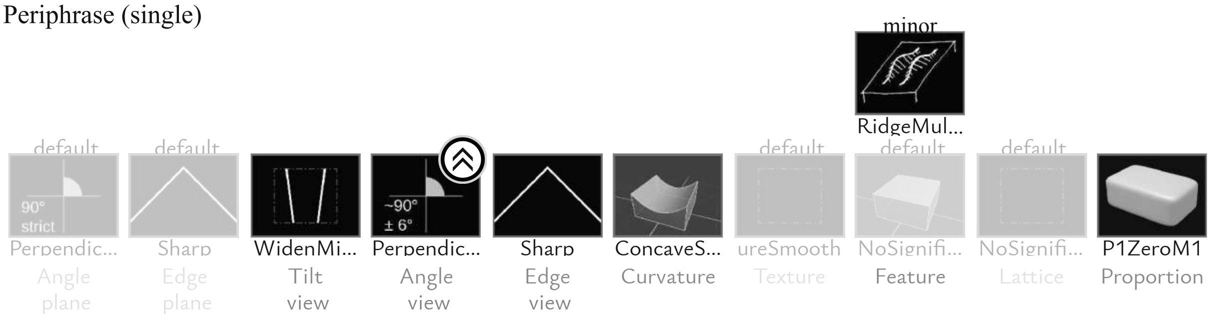
3. <Panoramio_user1476663_(cnUtf8)> 44412977

4. <BingMaps>

5. <Flickr_userMeiguoxing> 4569797067_c9fe428823_z

Group:	G - Concave (Position: 4)	Year, City:	2010 Shanghai
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	br
Empirical Id:	emp-n-br	Brief:	Brazil
Internal Ids:	prj2108, rep224, itm213	Full:	Brazil Pavilion
Tags:	expo2010/n-pav-br/nn-brazil	Qualified:	(see headline)

Periphrase (single)



This page intentionally left blank in print layout

G5 - Expo 1967 Italy Pavilion (Montreal)

1. <Flickr_userBdutfield> 3090633791_b84504c9f9_o

2. <Expo67NcfCa> expo67_construction_italy_pavilion

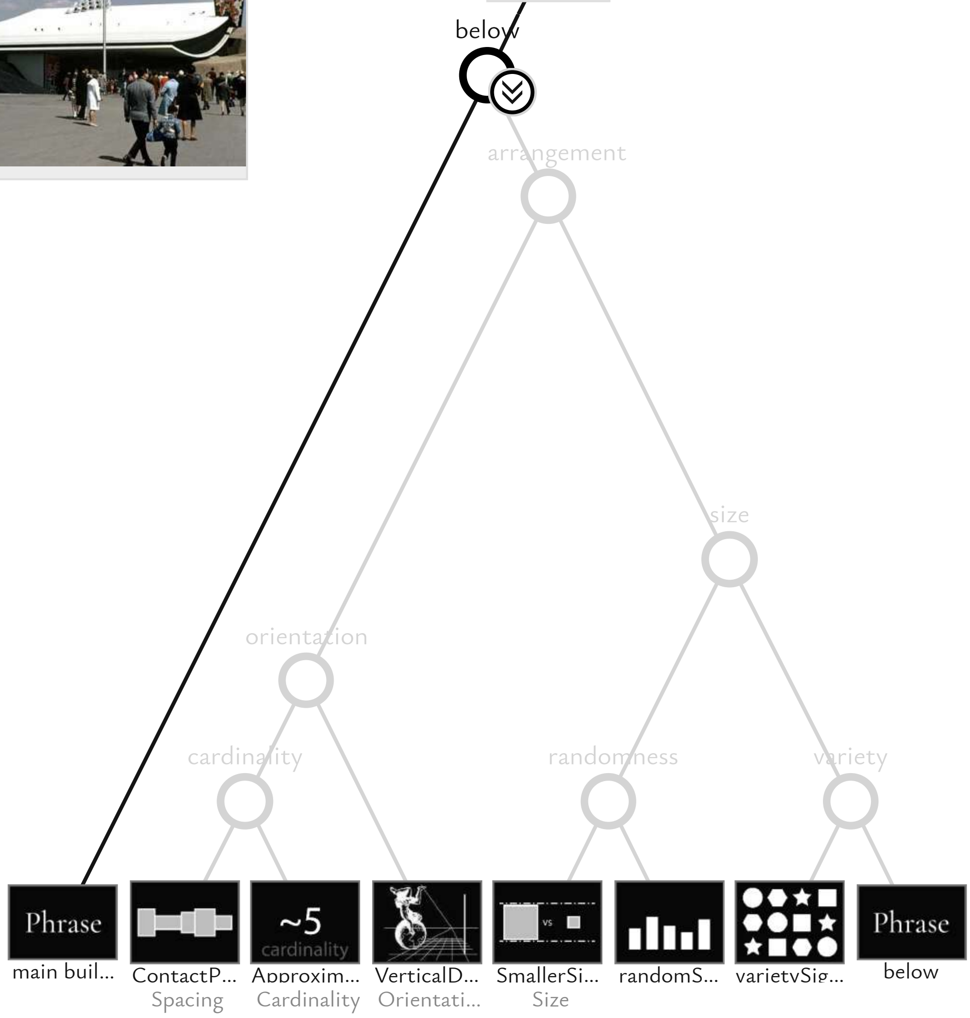
3. <Flickr_userBdutfield> 3090511741_b06a220f55_o

4. <ArchivesdemontrealIcaAtomOrg> VM94-EX281-012

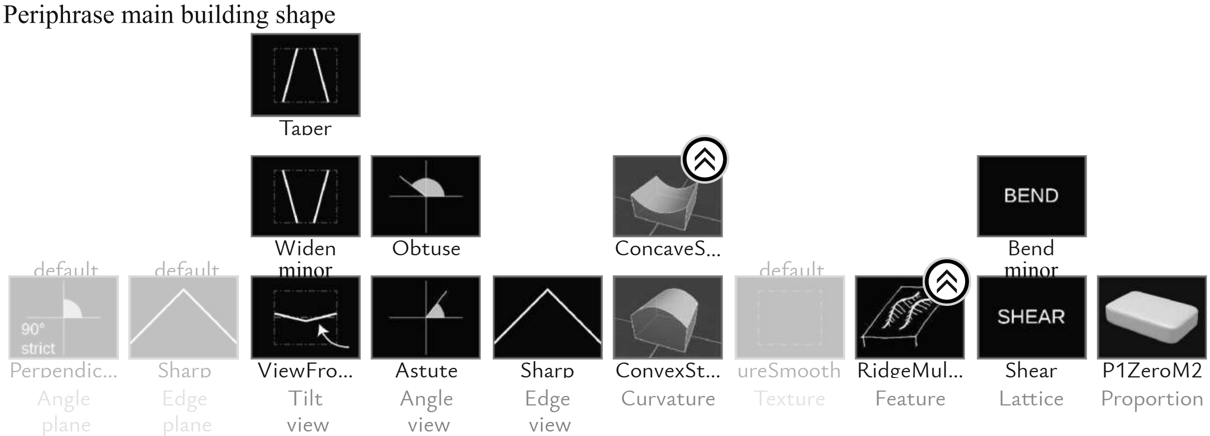
5. <Flickr_userMagstb67> 8462719221_6816c16ebe_o

Group:	G - Concave (Position: 5)	Year, City:	1967 Montreal
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	it67
Empirical Id:	emp-n-it67	Brief:	Italy (1967)
Internal Ids:	prj2416, rep223, itm223	Full:	Italy Pavilion
Tags:	expo1967/n-pav-it/nn-italia	Qualified:	(see headline)

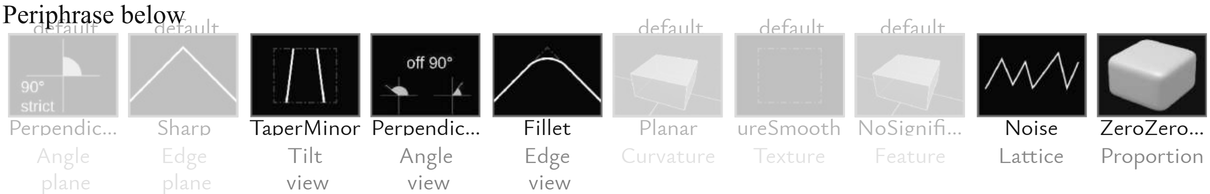
G5 - Expo 1967 Italy Pavilion (Montreal)



Periphrase main building shape

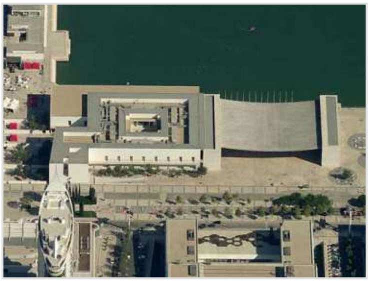


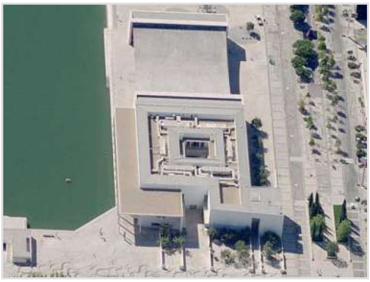
Periphrase below



G6 - Expo 1998 Portugal Host Pavilion (Lisboa)


1. <PJ> P1050751


2. <BingMaps> 05


3. <BingMaps> 03


4. <Panoramio_user84422NunoMiguelPaisTrabulo> 1870859


5. <Panoramio_user1558204Rucativaca> 35439124


6. <PJ> P1050749

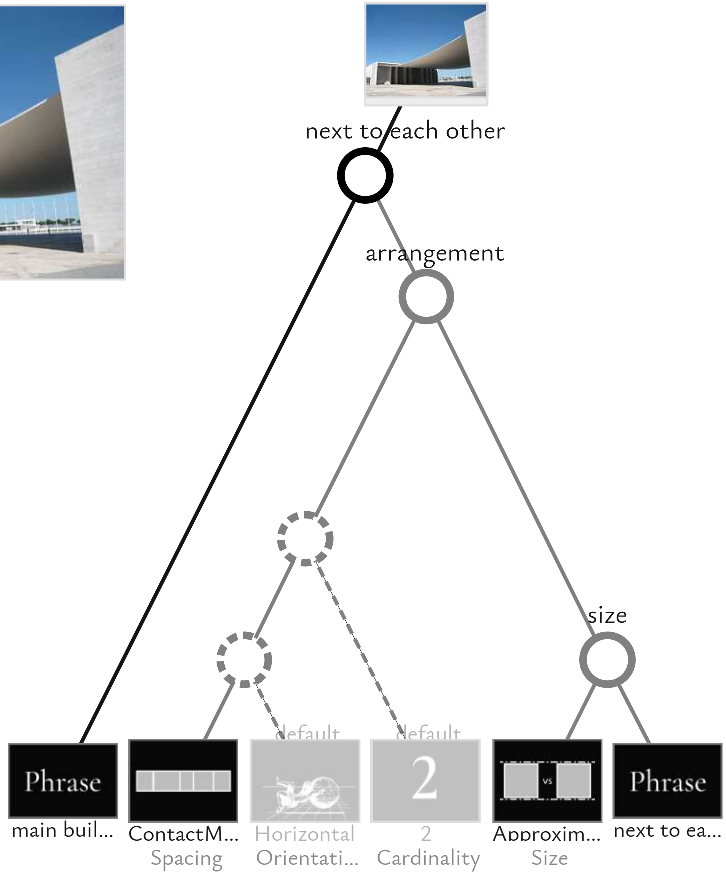

7. <PJ> P1050738


8. <PJ> P1050733

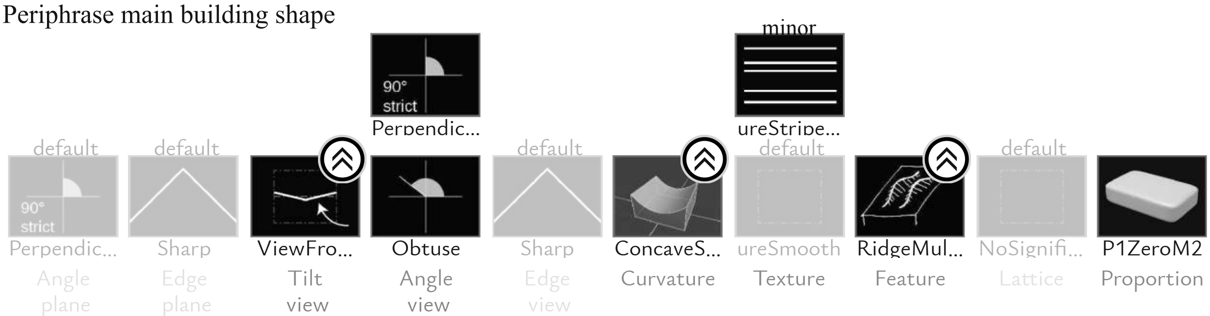

9. <PJ> P1050747

Group:	G - Concave (Position: 6)	Year, City:	1998 Lisboa
Pavilion Type:	Host Building (host)	Shortest:	h-pt
Empirical Id:	emp-host-pt	Brief:	Portugal
Internal Ids:	prj2701, rep222, itm227	Full:	Portugal Host Pavilion
Tags:	expo1998/host/hn-portugal	Qualified:	(see headline)

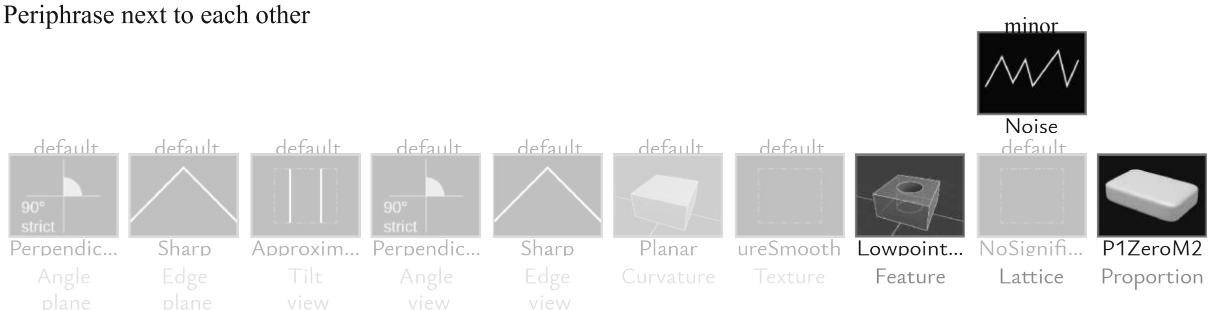
G6 - Expo 1998 Portugal Host Pavilion (Lisboa)



Periphrase main building shape



Periphrase next to each other



G7 - Expo 1970 Textiles Corporate Pavilion (Osaka)

1. <24621953AtlebryInfo_byTetsuo> 1323610946514132194 35_osak-ban-sen

2. <Flickr_userMLouis> 11827 80729_27670598a5_o

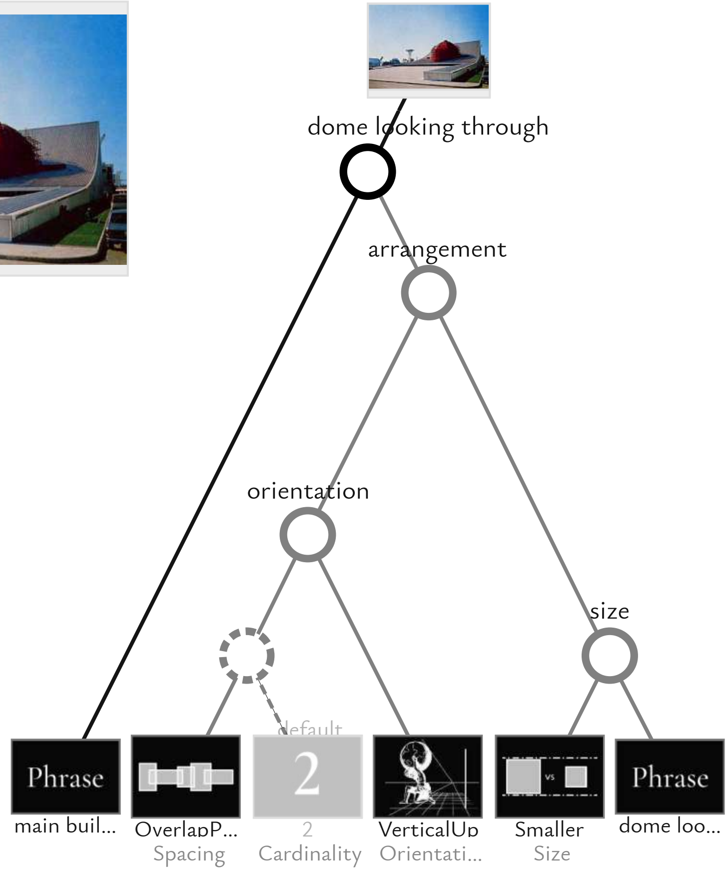
3. <YouTube_userRichOglesby> 6NnxVGWzR_Y_15

4. <NiftyComSaekiSin> seni2_xnconverted

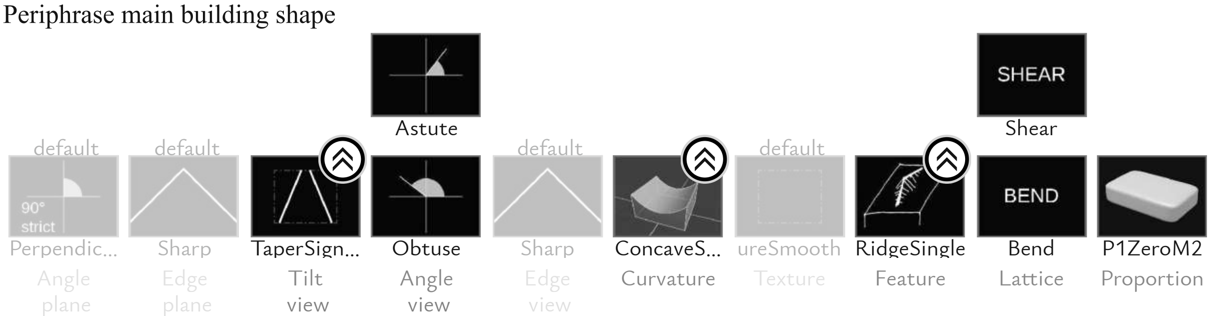
5. <AstudejaoublieBlogspotFr_byFukudaCard> japon14

Group:	G - Concave (Position: 7)	Year, City:	1970 Osaka
Pavilion Type:	Corporate Pavilion (c-pav)	Shortest:	tex
Empirical Id:	emp-c-textiles	Brief:	Textiles
Internal Ids:	prj3262, rep233, itm231	Full:	Textiles Corporate Pavilion
Tags:	expo1970/c-pav/cn-textiles	Qualified:	(see headline)

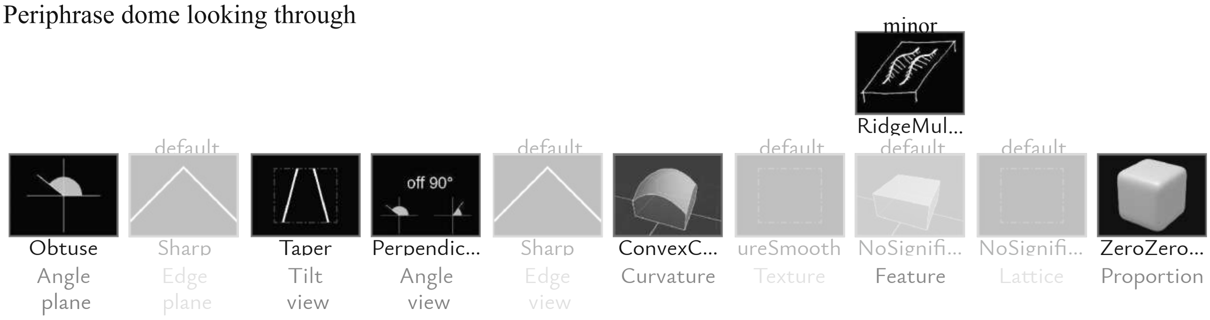
G7 - Expo 1970 Textiles Corporate Pavilion (Osaka)



Periphrase main building shape



Periphrase dome looking through



H1 - Expo 2010 Chile Pavilion (Shanghai)

1. <Expo2010ShanghaiChinaFromTheAir> expo0026

2. <Flickr_userKimon> 4694626340_0d7914b103_o

3. <Flickr_userFrankschacht> 4629685260_55fe902d13_b

4. <BingMaps>

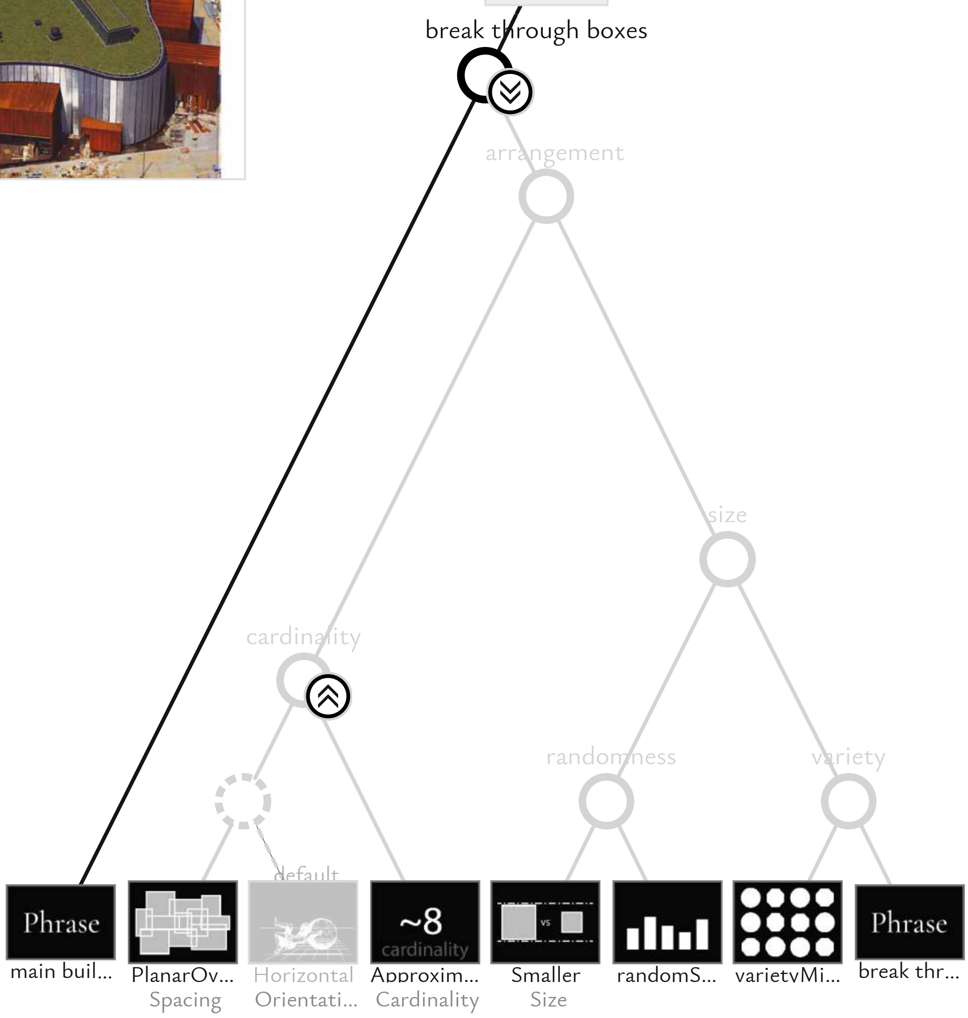
5. <Flickr_userWojtekgurak> 5487429528_2534233d67_o

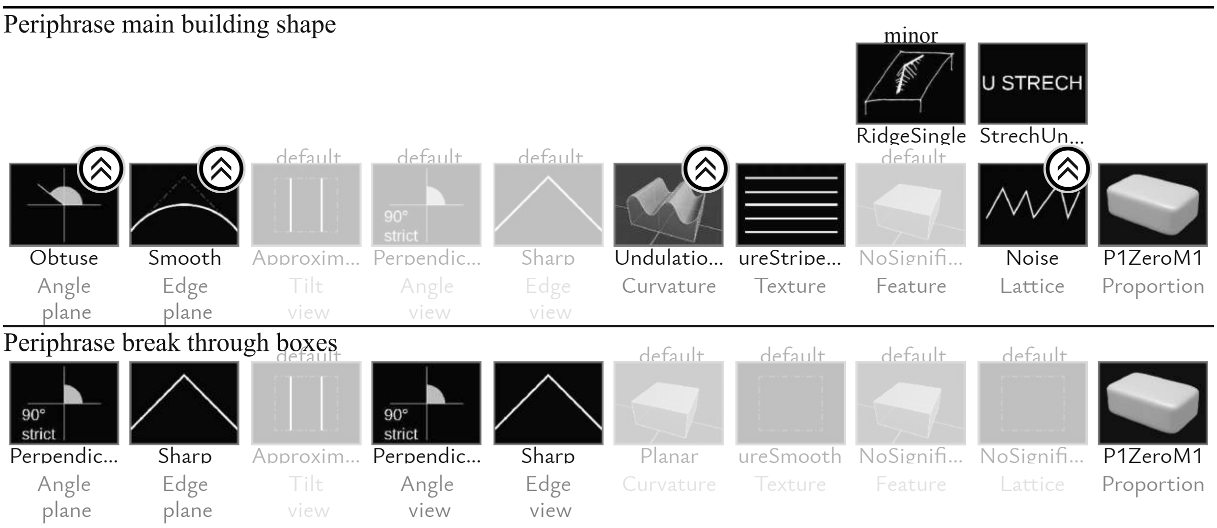
6. <Flickr_userWojtekgurak> 5486834339_7f7f2f2e41_o

7. <Expo2010ShanghaiChinaFromTheAir> 164

Group:	H - Undulation (Position: 1)	Year, City:	2010 Shanghai
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	cl
Empirical Id:	emp-n-cl	Brief:	Chile
Internal Ids:	prj2112, rep226, itm196	Full:	Chile Pavilion
Tags:	expo2010/n-pav-cl/nn-chile	Qualified:	(see headline)

H1 - Expo 2010 Chile Pavilion (Shanghai)





H2 - Expo 2010 Info Communication Corp. Pav. (Shanghai)

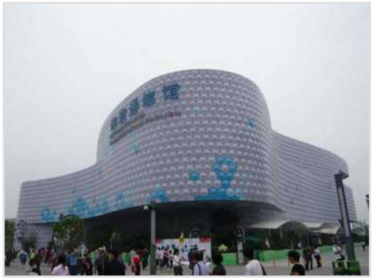
1. <Expo2010ShanghaiChinaFromTheAir> expo0044c

2. <Expo2010ShanghaiChinaFromTheAir> expo0042d

3. <Flickr_userKimon> 4633166865_93dd6c25a9_o

4. <PJ> 1040413

5. <PJ> 1040404



6. <PJ> 1040407

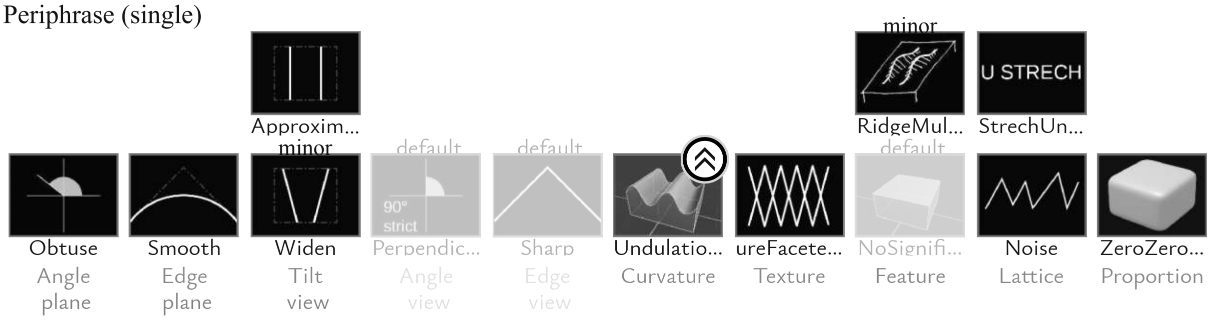
7. <Flickr_userBellchan> 5690217253_9f1337da60_b

8. <Flickr_userExpomuseum> 4687812946_3b01733b32_o

9. <BingMaps>

Group:	H - Undulation (Position: 2)	Year, City:	2010 Shanghai
Pavilion Type:	Corporate Pavilion (c-pav)	Shortest:	info
Empirical Id:	emp-c-info	Brief:	Info Communication
Internal Ids:	prj2268, rep228, itm193	Full:	Info Communication Corporate Pavilion
Tags:	expo2010/c-pav/cn-infoCommunication	Qualified:	(see headline)

Periphrase (single)



This page intentionally left blank in print layout

H3 - Expo 2010 Australia Pavilion (Shanghai)

1. <Flickr_userWojtekgurak> 5 469176217_63aaf97127_o

2. <Flickr_userWojtekgurak> 5 469770110_ac5d1f23f2_o

3. <Flickr_userFrankschacht> 4 713156513_f7f01875b1_b

4. <Expo2010ShanghaiChinaFromTheAir> expo0007

5. <GoogleMaps>

6. <Flickr_userExpomuseum> 4 684711554_41ddbdd0da_o

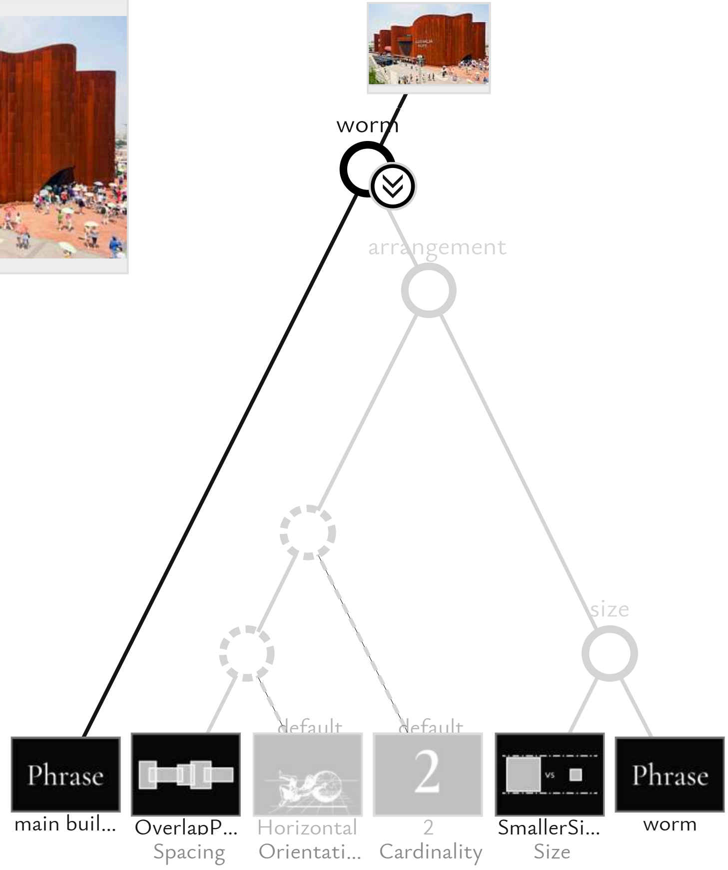
7. <Flickr_userWojtekgurak> 5 469770226_f0d2c6dfe3_o

8. <Panoramio_user1400530_(utf8_1961)> 37481962

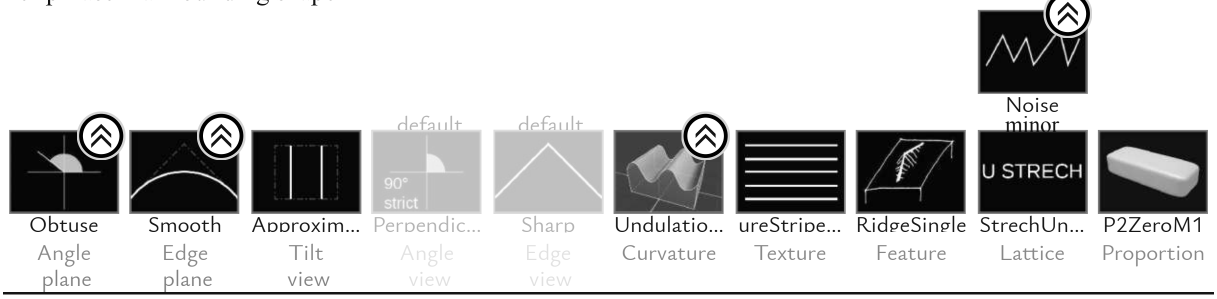
9. <Flickr_userCesarCorona> 4 926630803_9535c0dbfe_o

Group:	H - Undulation (Position: 3)	Year, City:	2010 Shanghai
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	au10
Empirical Id:	emp-n-au10	Brief:	Australia (2010)
Internal Ids:	prj2104, rep227, itm263	Full:	Australia Pavilion
Tags:	expo2010/n-pav-au/nn-australia	Qualified:	(see headline)

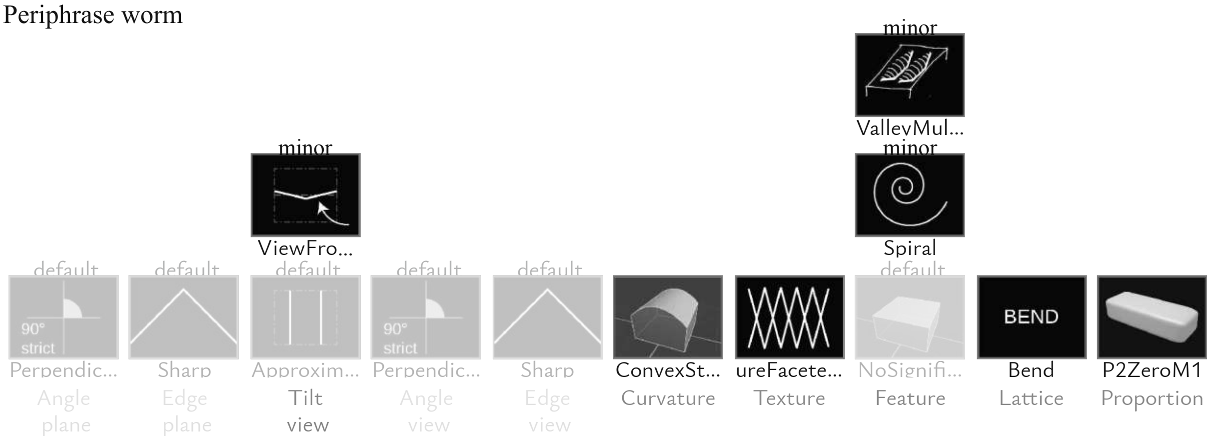
H3 - Expo 2010 Australia Pavilion (Shanghai)



Periphrase main building shape

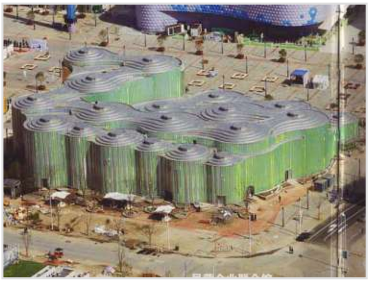


Periphrase worm



H4 - Expo 2010 Private Enterprise Corp. Pav. (Shanghai)


1. <Expo2010ShanghaiChinaFromTheAir> expo0047a


2. <Expo2010ShanghaiChinaFromTheAir> expo0044b


3. <Panoramio_user6501470_(utf8)> 63756400


4. <PJ> 1040405


5. <GoogleMaps>


6. <Panoramio_user557748(jsduo44)> 38676071

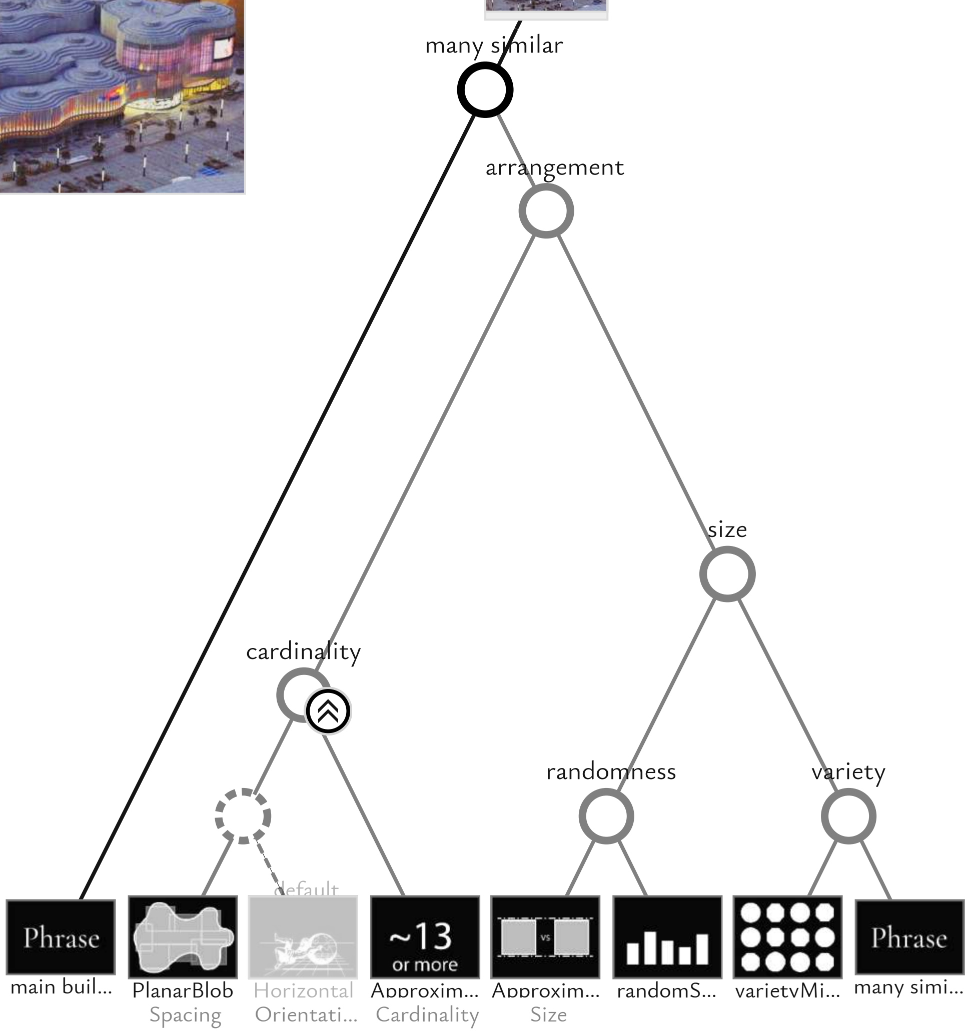

7. <Flickr_userExpomuseum> 4704772787_4a2563e3f4_o


8. <Flickr_userKimon> 4633133649_22740ec6be_o

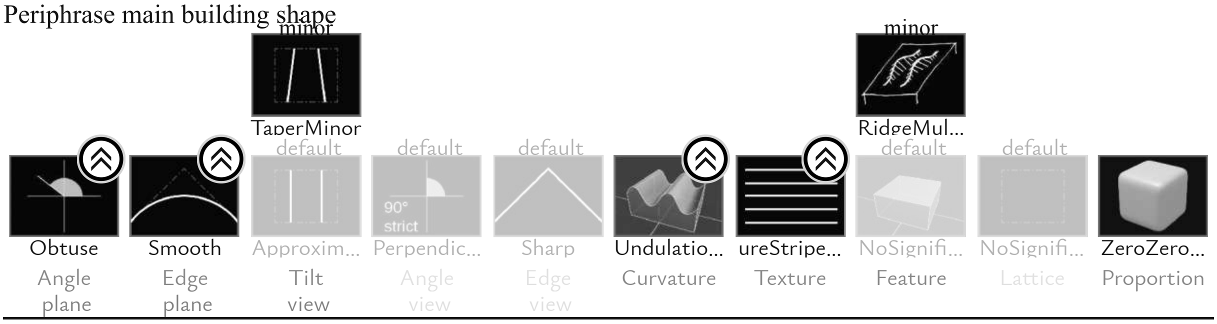

9. <Panoramio_user1400530_(utf8_1961)> 37531721

Group:	H - Undulation (Position: 4)	Year, City:	2010 Shanghai
Pavilion Type:	Corporate Pavilion (c-pav)	Shortest:	priv
Empirical Id:	emp-c-private	Brief:	Private Enterprise
Internal Ids:	prj2273, rep229, itm229	Full:	Private Enterprise Corporate Pavilion
Tags:	expo2010/c-pav/cn-privateEnterprise	Qualified:	(see headline)

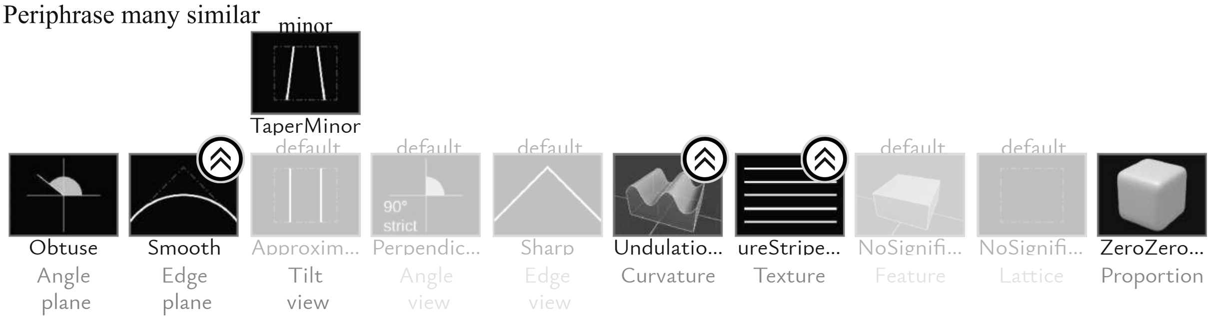
H4 - Expo 2010 Private Enterprise Corp. Pav. (Shanghai)



Periphrase main building shape



Periphrase many similar



H5 - Expo 2010 Spain Pavilion (Shanghai)

1. <Expo2010ShanghaiChinaFromTheAir> 167

2. <BingMaps>

3. <Flickr_userSteelersliu> 4893606848_6cd31ab187_o

4. <StatesOfArchitectures_byNicLehoux> 2

5. <Flickr_userSteelersliu> 4893009123_97a3e9c62d_o

6. <PJ> 1040214

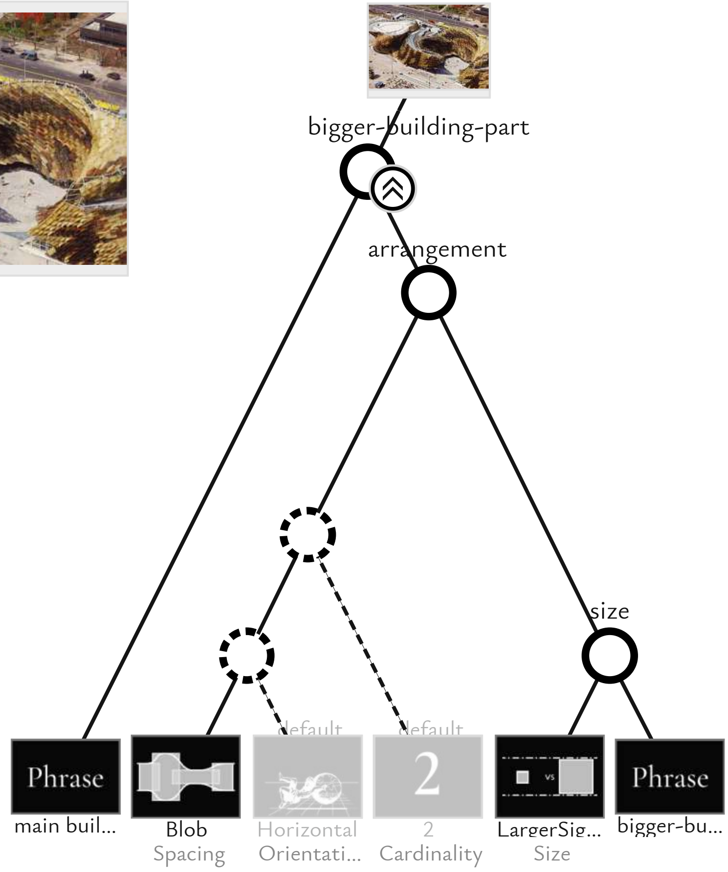
7. <Flickr_userChimaybleue> 4729950594_5e21978b54_b

8. <Panoramio_user604433_(吉易)> 37093562

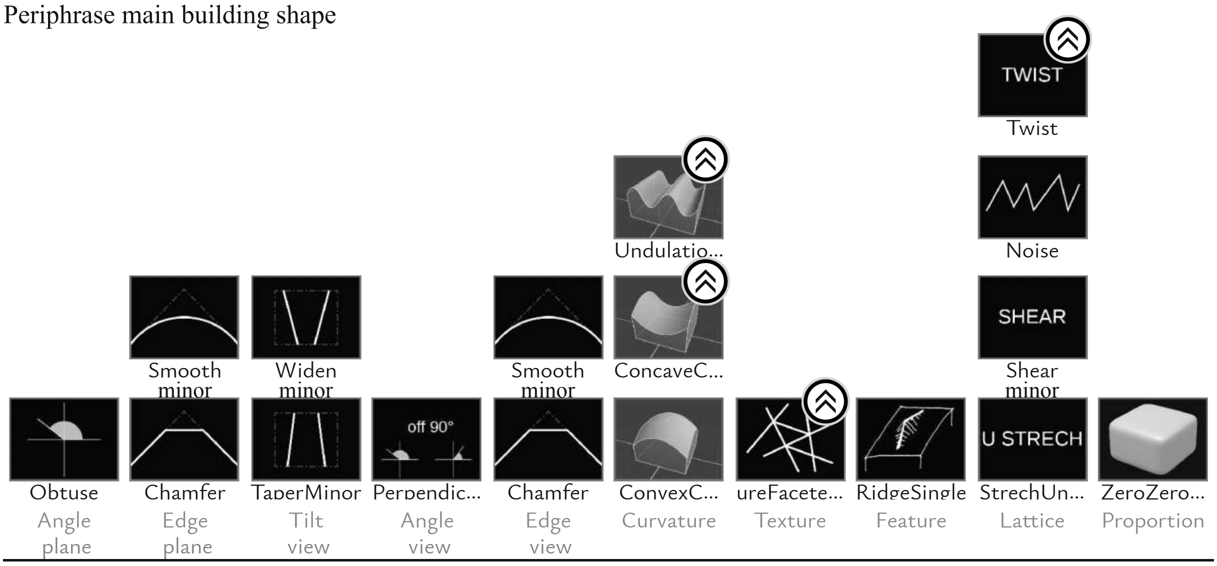
9. <Flickr_userFrankschacht> 4926750112_ed1d8d004a_b

Group:	H - Undulation (Position: 5)	Year, City:	2010 Shanghai
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	es
Empirical Id:	emp-n-es	Brief:	Spain
Internal Ids:	prj2121, rep230, itm202	Full:	Spain Pavilion
Tags:	expo2010/n-pav-es/nn-spain	Qualified:	(see headline)

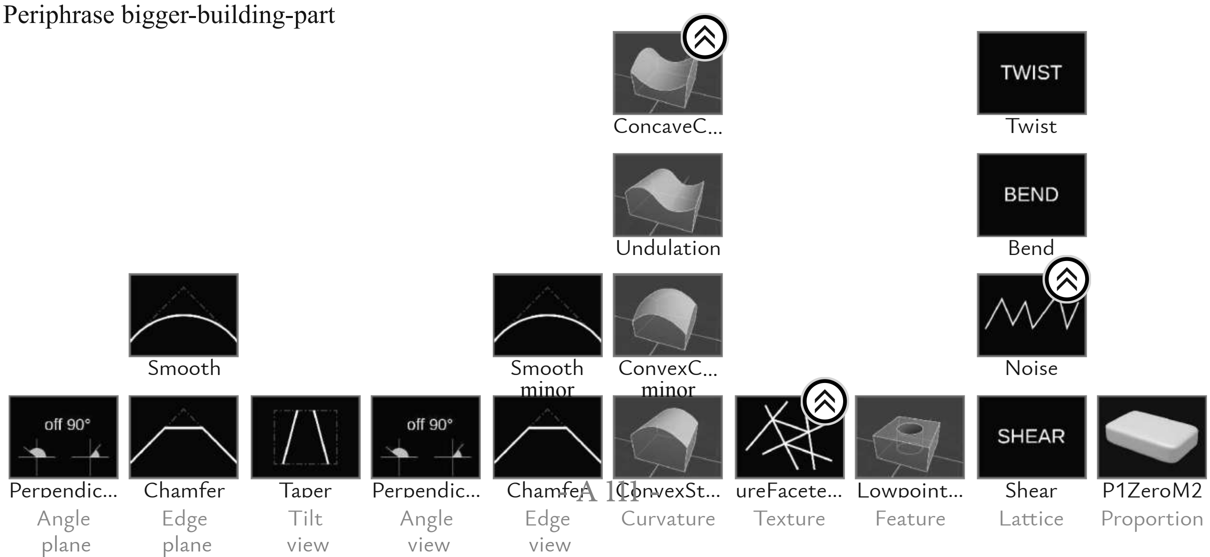
H5 - Expo 2010 Spain Pavilion (Shanghai)



Periphrase main building shape



Periphrase bigger-building-part



H6 - Expo 1992 Palaza Del Futuro Theme Pavilion (Sevilla)

1. <PJ> espana-1030389

2. <BingMaps> 5

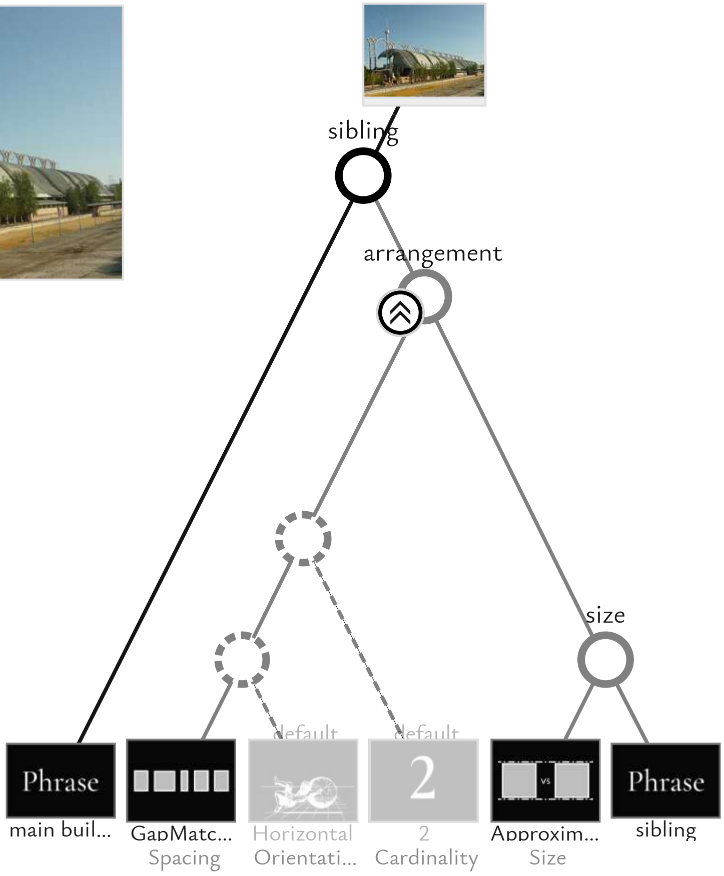
3. <PJ> espana-1030387

4. <PJ> espana-1030475

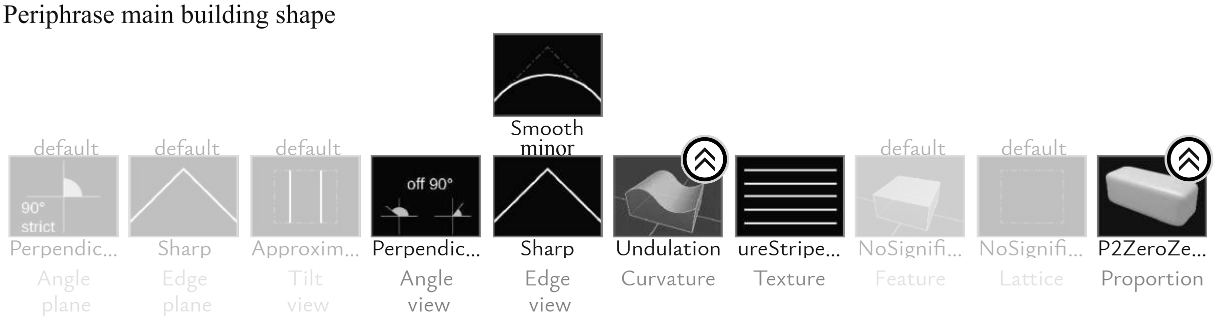
5. <BingMaps> 2

Group:	H - Undulation (Position: 6)	Year, City:	1992 Sevilla
Pavilion Type:	Theme Pavilion (t-pav)	Shortest:	pfu
Empirical Id:	emp-t-futuro	Brief:	Palaza Del Futuro
Internal Ids:	prj2837, rep231, itm258	Full:	Palaza Del Futuro Theme Pavilion
Tags:	expo1992/t-pav/tn-palazaDelFuturo	Qualified:	(see headline)

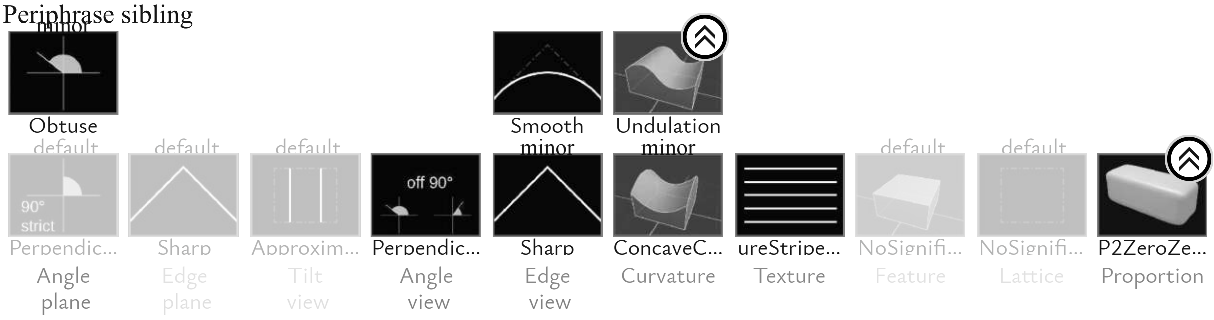
H6 - Expo 1992 Palaza Del Futuro Theme Pavilion (Sevilla)



Periphrase main building shape



Periphrase sibling



H7 - Expo 2000 Hungary Pavilion (Hannover)


1. <Panoramio_user775448-brickl> 32940691


2. <Flickr_userPittigliani2005> 194926529_bc42704c8c_o


3. <Panoramio_user775448-brickl> 32940675


4. <GoogleEarth> y2006_n-pav-hu


5. <ArchitectureExpo2000Hannover> IMG_1119


6. <Flickr_userHansziel> 4674640205_e447c91c8e_o

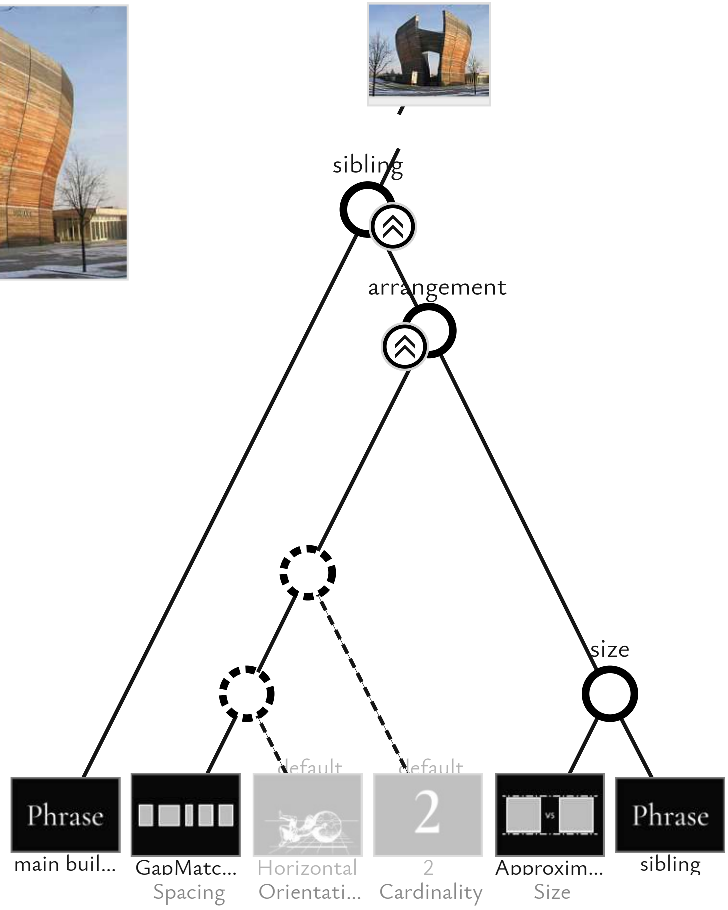

7. <Flickr_userExpomuseum> 67848981_269d424ce9_o


8. <Flickr_userExpomuseum> 67849052_a06aea0ac4_o

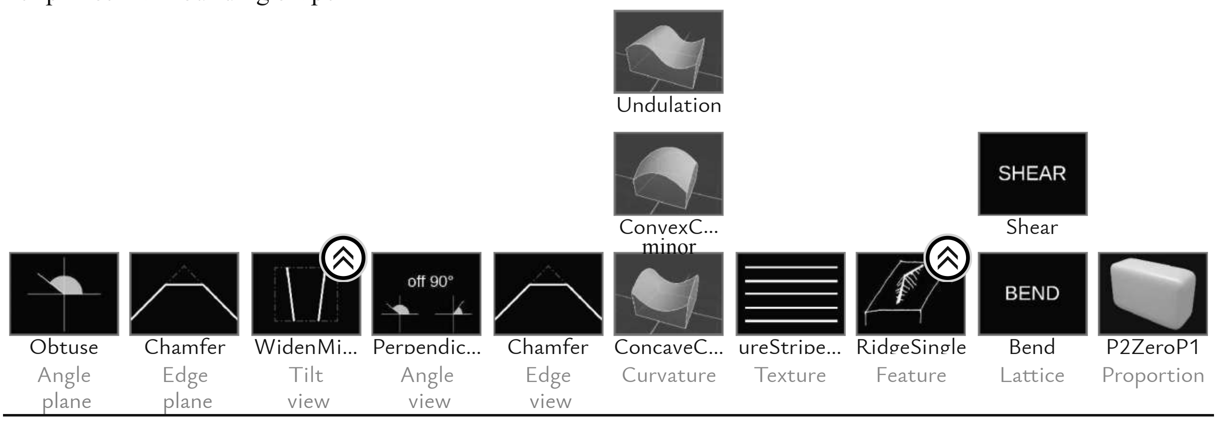

9. <Wikipedia_byBallonSzDe> Expogelände_Heute_(2007)c

Group:	H - Undulation (Position: 7)	Year, City:	2000 Hannover
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	hu
Empirical Id:	emp-n-hu	Brief:	Hungary
Internal Ids:	prj3418, rep232, itm240	Full:	Hungary Pavilion
Tags:	expo2000/n-pav-hu	Qualified:	(see headline)

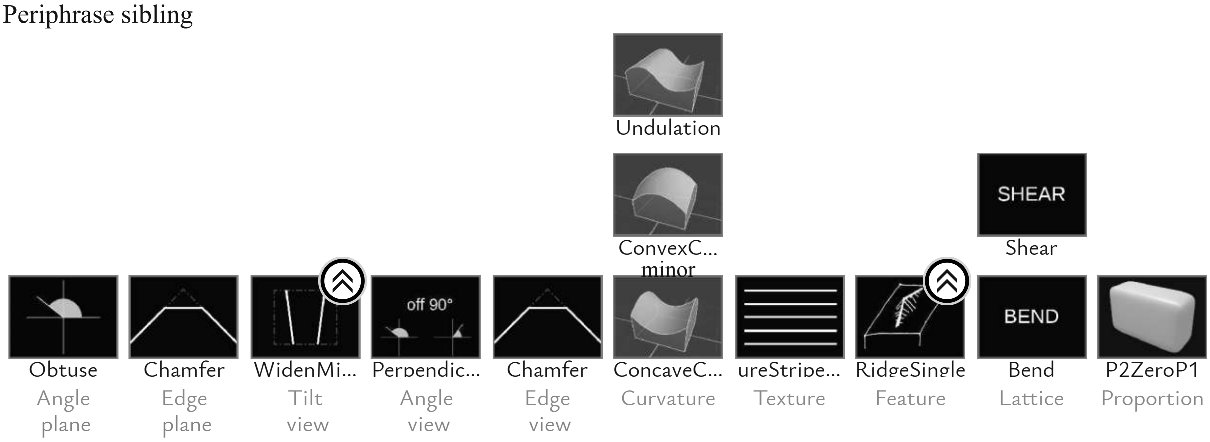
H7 - Expo 2000 Hungary Pavilion (Hannover)



Periphrase main building shape



Periphrase sibling



S1 - Expo 2010 France Pavilion (Shanghai)

1. <Expo2010ShanghaiChinaFromTheAir> expo0020a

2. <Flickr_userKhoavo> 4564984095_86e093d102_o

3. <GoogleMaps>

4. <Flickr_userKimon> 4686474691_48b817dd38_o

5. <Flickr_userDisneykid> 5432966108_ed79ef7a9f_b

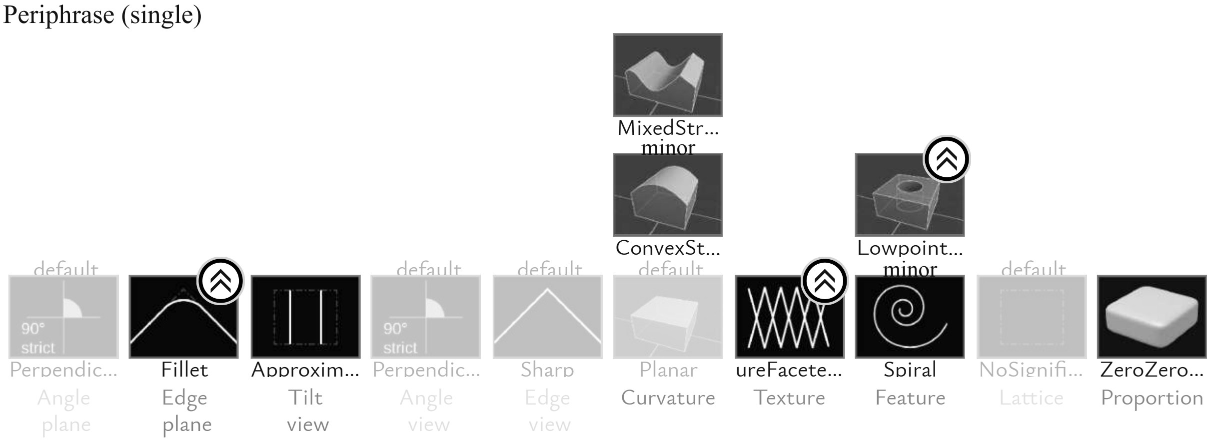
6. <StatesOfArchitectures_byNicLehoux> 1

7. <Flickr_userMrTl> 4923166626_7b651b421d_b

8. <Flickr_userKommandokraus> 4647809816_ae3fb4d8a9_o

Group:	S - Truncation Hole (Position: 1)	Year, City:	2010 Shanghai
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	fr10
Empirical Id:	emp-n-fr10	Brief:	France (2010)
Internal Ids:	prj2123, rep234, itm248	Full:	France Pavilion (2010)
Tags:	expo2010/n-pav-fr/nn-france	Qualified:	(see headline)

Periphrase (single)



S2 - Expo 2010 Finland Pavilion (Shanghai)

1. <Flickr_userSteelersliu> 489 3608054_420b9fc5b2_o

2. <GoogleMaps>

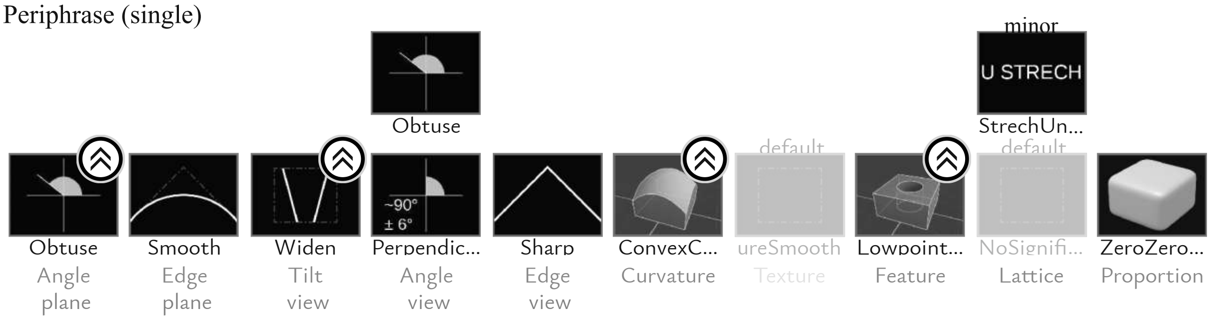
3. <StatesOfArchitectures_by NicLehoux> 1

4. <Flickr_userWojtekgurak> 5 510816494_6203fb1d0b_o

5. <Expo2010ShanghaiChinaFr omTheAir> expo0035

Group:	S - Truncation Hole (Position: 2)	Year, City:	2010 Shanghai
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	fi
Empirical Id:	emp-n-fi	Brief:	Finland
Internal Ids:	prj2122, rep235, itm205	Full:	Finland Pavilion
Tags:	expo2010/n-pav-fi/nn-finland	Qualified:	(see headline)

Periphrase (single)



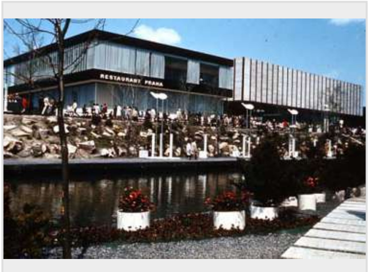
S3 - Expo 1967 Czechoslovakia Pavilion (Montreal)

1. <AlamedainfoCom> expo_67_Montreal_Canada_The_Czechoslovak_Pavilion_ADEX314


2. <CollectionscanadaGcCa> e000990856


3. <CollectionscanadaGcCa> e000990865

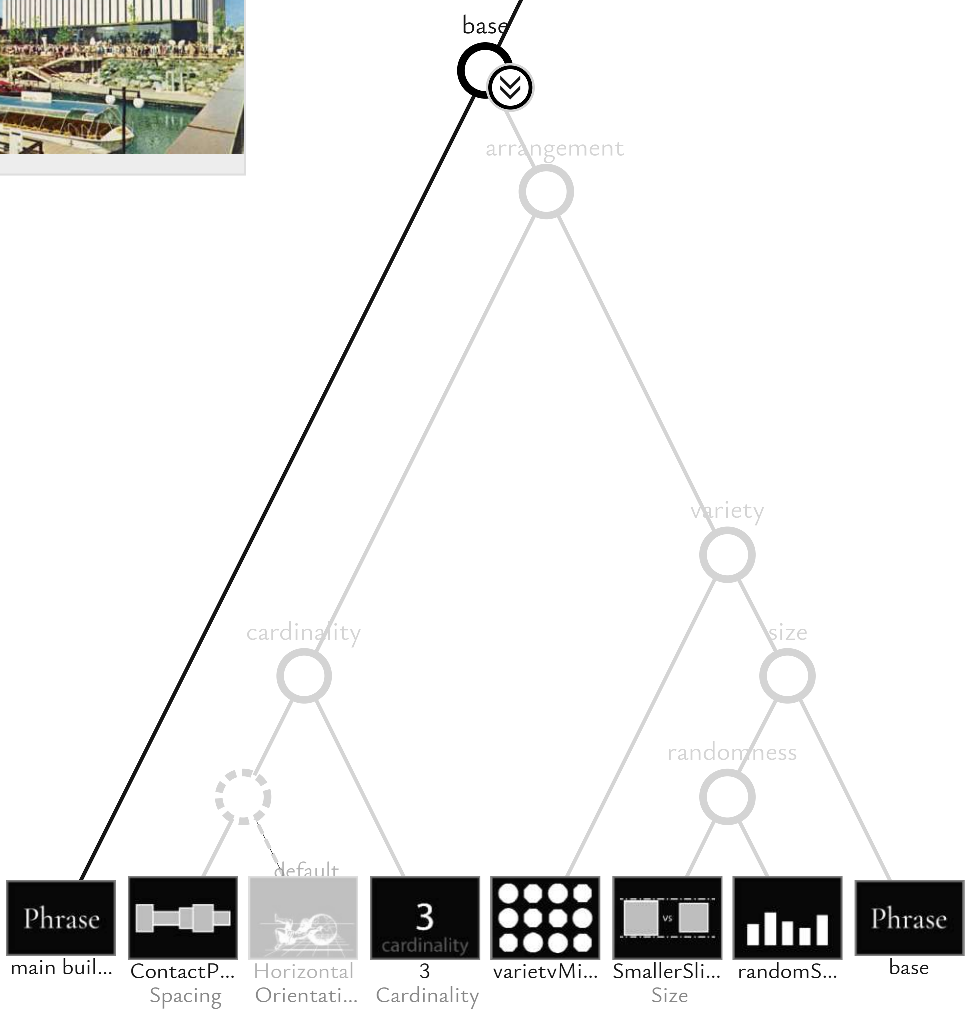

4. <Flickr_userJeffs4653> 3949130058_b056125550_b



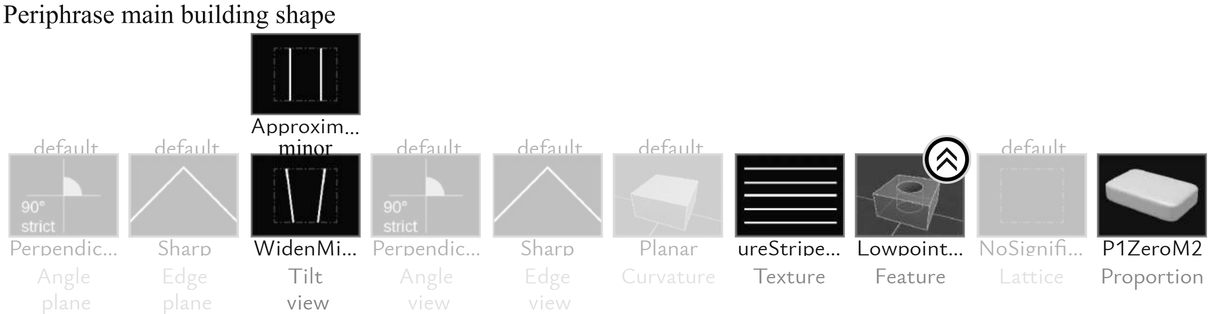
5. <ArchivesdemontrealIcaAtomOrg> VM94-EX281-062

Group:	S - Truncation Hole (Position: 3)	Year, City:	1967 Montreal
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	cz
Empirical Id:	emp-n-cz	Brief:	Czechoslovakia
Internal Ids:	prj2406, rep236, itm195	Full:	Czechoslovakia Pavilion
Tags:	expo1967/n-pav-cz/nn-czechRepublic	Qualified:	(see headline)

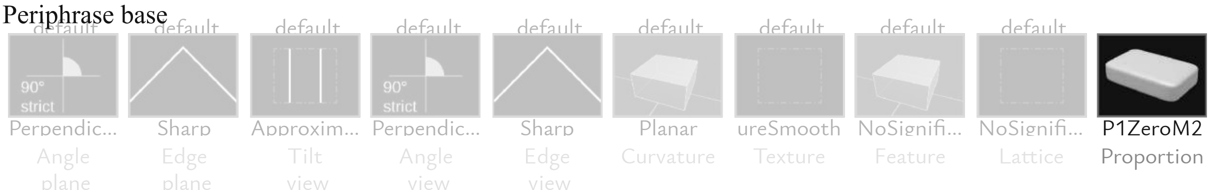
S3 - Expo 1967 Czechoslovakia Pavilion (Montreal)



Periphrase main building shape



Periphrase base



T1 - Expo 2012 Samsunung Corporate Pavilion (Yeosu)

1. <Panoramio_user(utf8)_(3705168)> 76721995

2. <Flickr_userIweatherman> 7267999774_6db0c47805_o

3. <Panoramio_userPlumgarden_(54048)> 76636280

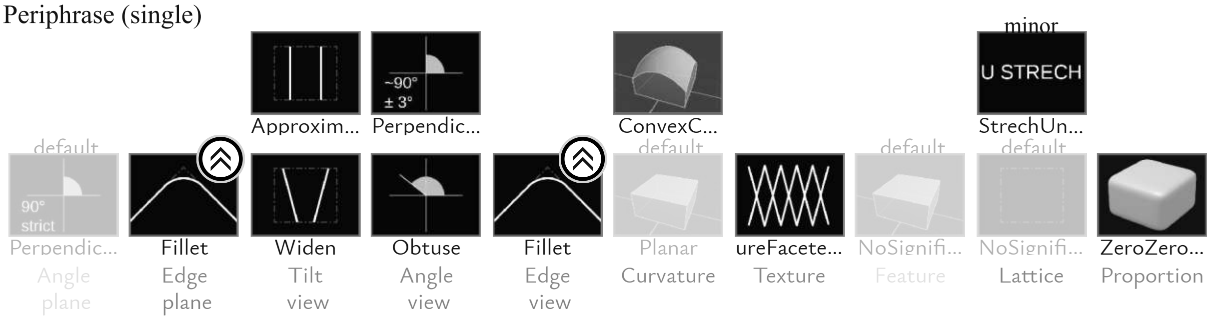
4. <Panoramio_userPlumgarden_(54048)> 76696966

5. <Flickr_userCesarCorona> 7167769559_6681accb96_o

6. <Flickr_userTravelingchris1972> 7232865620_9a248f2fa6_o

Group:	T - Truncation Corner (Position: 1)	Year, City:	2012 Yeosu
Pavilion Type:	Corporate Pavilion (c-pav)	Shortest:	sams
Empirical Id:	emp-c-samsung	Brief:	Samsung
Internal Ids:	prj2658, rep237, itm212	Full:	Samsunung Corporate Pavilion
Tags:	expo2012/c-pav/cn-samsung	Qualified:	(see headline)

Periphrase (single)



T2 - Expo 2010 Oil Corporate Pavilion (Shanghai)

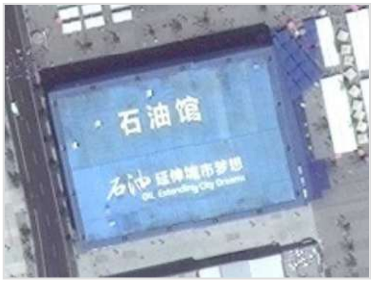
1. <Flickr_userKimon> 4633716458_6870e80b8b_o

2. <Flickr_userWentaoYin12> 5197842695_9164785722_o

3. <Expo2010ShanghaiChinaFromTheAir> 125

4. <Expo2010ShanghaiChinaFromTheAir> 118

5. <Flickr_userDisneykid> 5412749724_da7f3e35d2_b

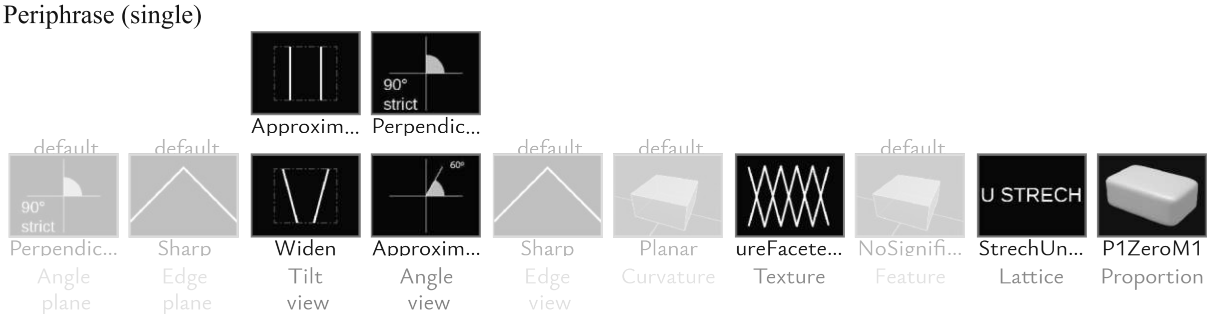


6. <BingMaps>

7. <Flickr_userWentaoYin12> 5198390574_26c61498c3_o

Group:	T - Truncation Corner (Position: 2)	Year, City:	2010 Shanghai
Pavilion Type:	Corporate Pavilion (c-pav)	Shortest:	oil
Empirical Id:	emp-c-oil	Brief:	Oil
Internal Ids:	prj2271, rep239, itm244	Full:	Oil Corporate Pavilion
Tags:	expo2010/c-pav/cn-oil	Qualified:	(see headline)

Periphrase (single)



T3 - Expo 2012 Posco Corporate Pavilion (Yeosu)

1. <Panoramio_user(utf8)_(3705168)> 76721979

2. <Flickr_userExpomuseum> 7835998380_546ef566e1_o

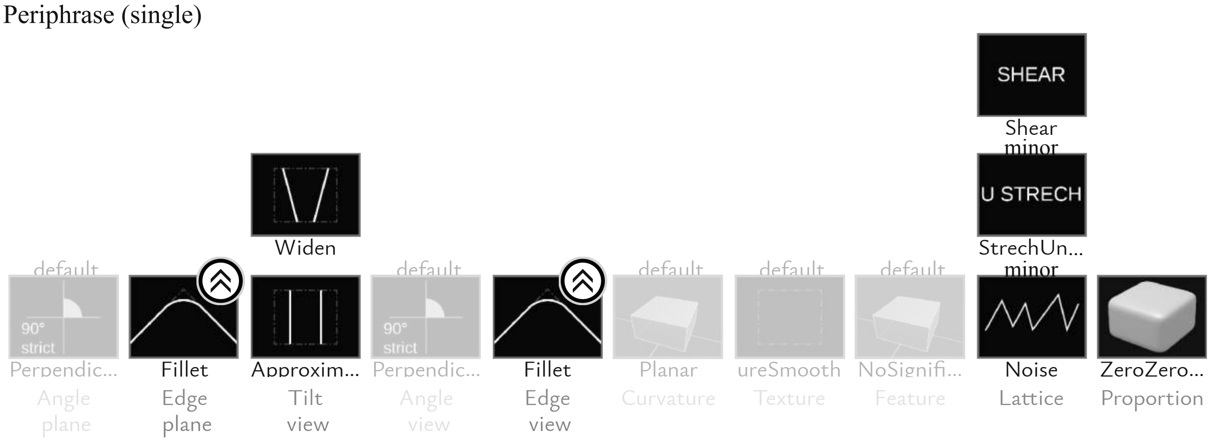
3. <Flickr_userDannyOei> 7555048056_d6c1b5850e_o

4. <Flickr_userExpomuseum> 7859980784_e277cf9a6a_o

5. <Panoramio_userPlumgarden_(54048)> 76578480

Group:	T - Truncation Corner (Position: 3)	Year, City:	2012 Yeosu
Pavilion Type:	Corporate Pavilion (c-pav)	Shortest:	pos
Empirical Id:	emp-c-posco	Brief:	Posco
Internal Ids:	prj2657, rep238, itm208	Full:	Posco Corporate Pavilion
Tags:	expo2012/c-pav/cn-posco	Qualified:	(see headline)

Periphrase (single)



This page intentionally left blank in print layout

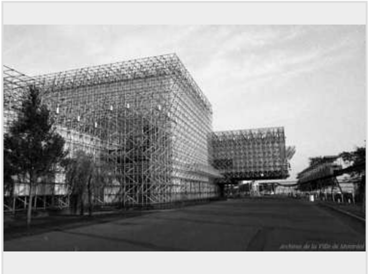
U1 - Expo 1967 Netherlands Pavilion (Montreal)

1. <Expo67NcfCa> z_netherlands

2. <ArchivesdemontrealIcaAtomOrg> VM94-B208-019

3. <ArchivesdemontrealIcaAtomOrg> VM94-EX136-167

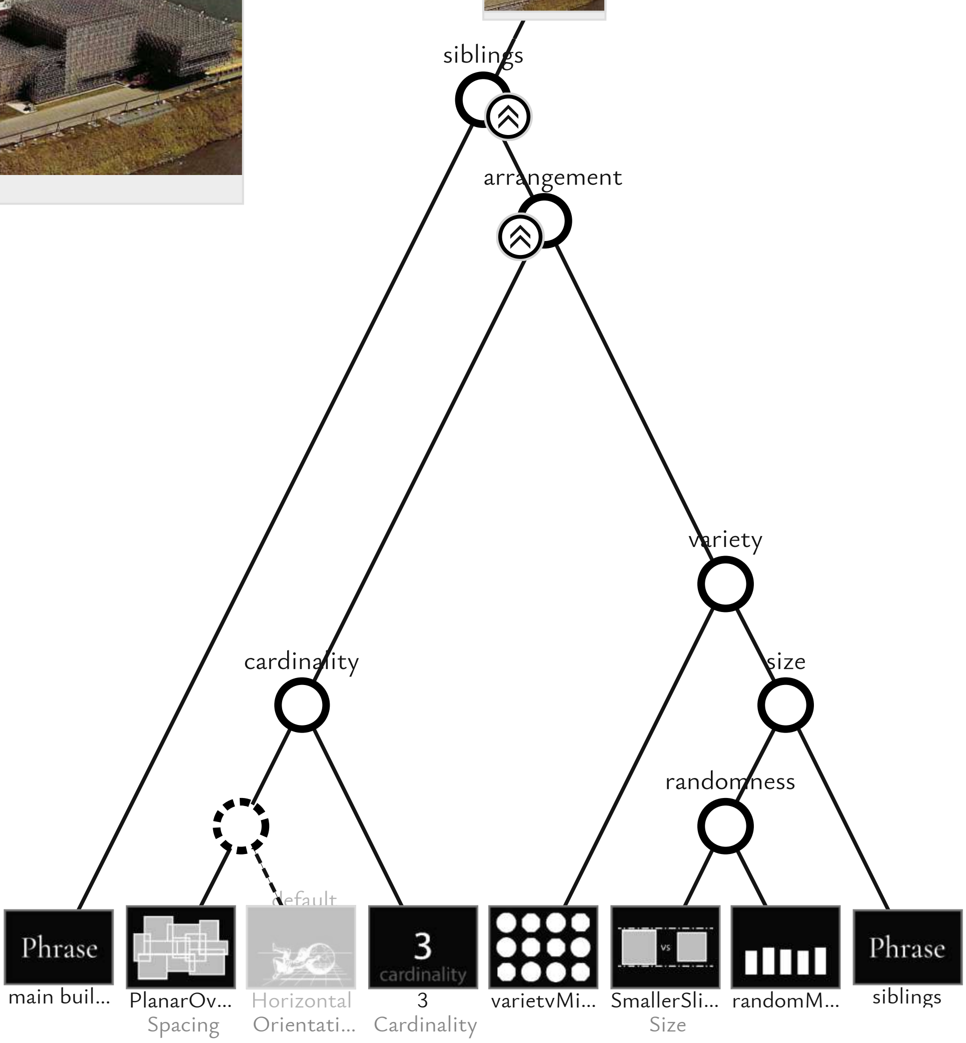
4. <ArchivesdemontrealIcaAtomOrg> VM94-EX136-881



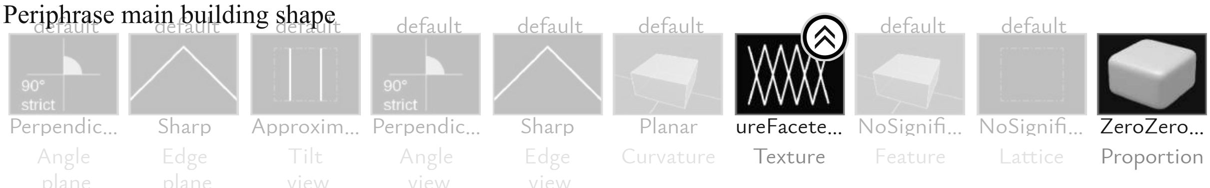
5. <ArchivesdemontrealIcaAtomOrg> VM94-EX136-882

Group:	U - Penetrate Boxes (Position: 1)	Year, City:	1967 Montreal
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	nl
Empirical Id:	emp-n-nl67	Brief:	Netherlands (1967)
Internal Ids:	prj2426, rep240, itm216	Full:	Netherlands Pavilion (1967)
Tags:	expo1967/n-pav-nl/nn-netherlands	Qualified:	(see headline)

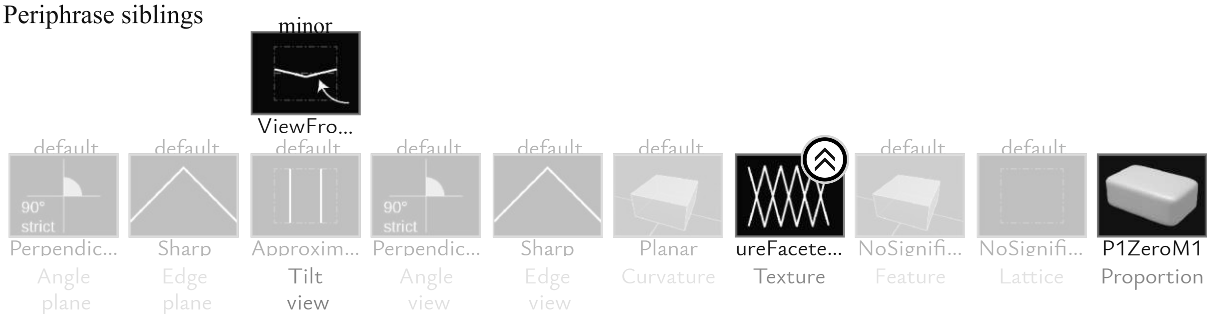
U1 - Expo 1967 Netherlands Pavilion (Montreal)



Periphrase main building shape



Periphrase siblings



U2 - Expo 2010 Hamburg Urban Pavilion (Shanghai)

1. <Panoramio_user239280_(Baycrest)> 56967092

2. <Flickr_userFrankschacht> 4926012894_6b6e64056b_b

3. <Flickr_userFrankschacht> 4926029800_90fb75a2cc_b

4. <BingMaps>

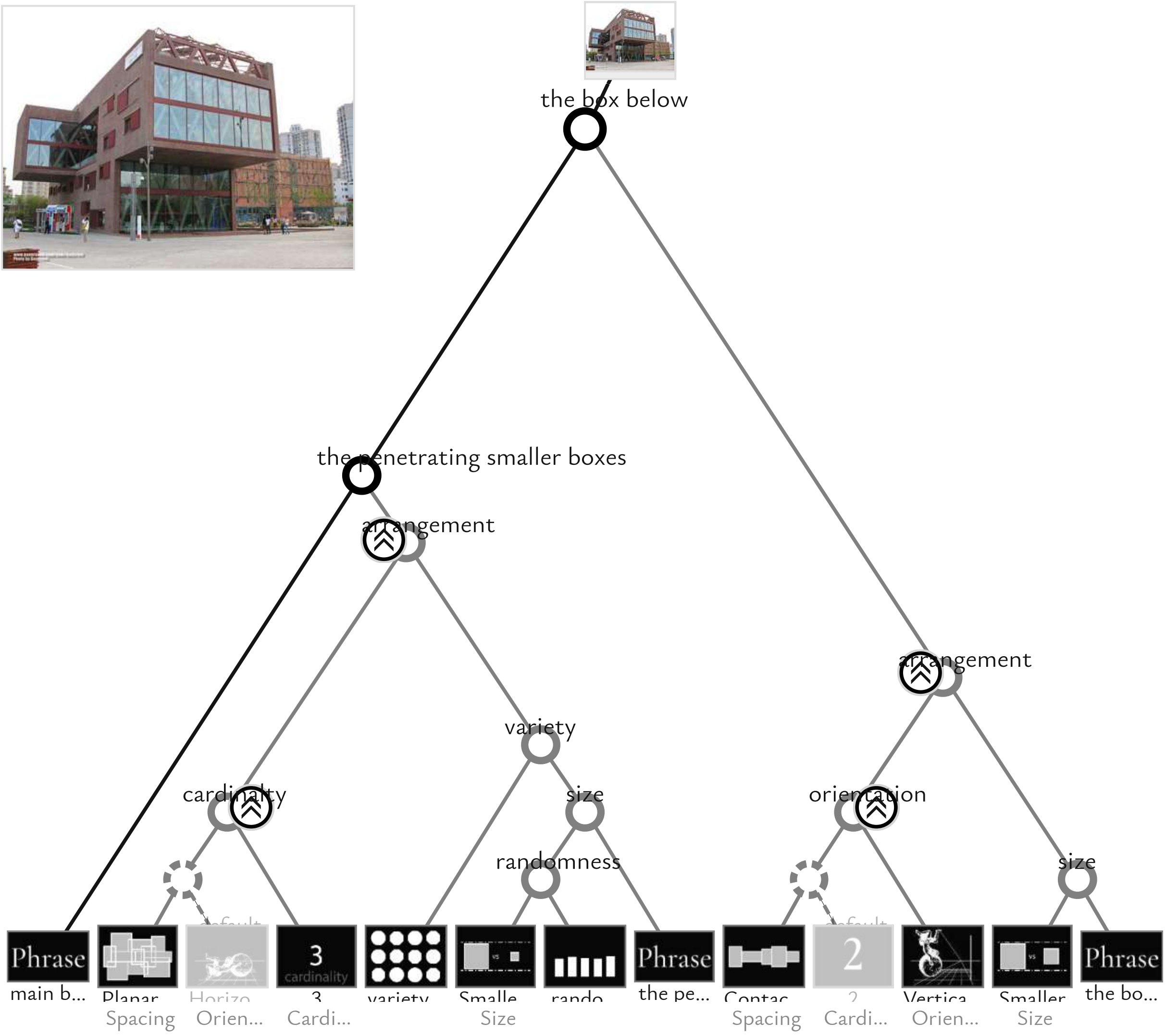
5. <Flickr_userFrankschacht> 4925597353_9b7639894e_b

6. <Flickr_userFrankschacht> 4925443199_4a2f6d46d6_b

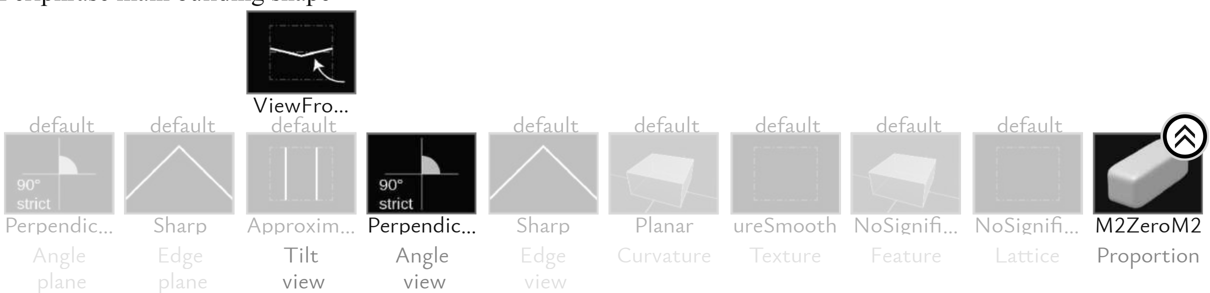
7. <Expo2010ShanghaiChinaFromTheAir> 180

Group:	U - Penetrate Boxes (Position: 2)	Year, City:	2010 Shanghai
Pavilion Type:	Urban Pavilion (u-pav)	Shortest:	ham
Empirical Id:	emp-u-hamburg	Brief:	Hamburg
Internal Ids:	prj2242, rep241, itm219	Full:	Hamburg Urban Pavilion
Tags:	expo2010/u-pav/un-hamburg	Qualified:	(see headline)

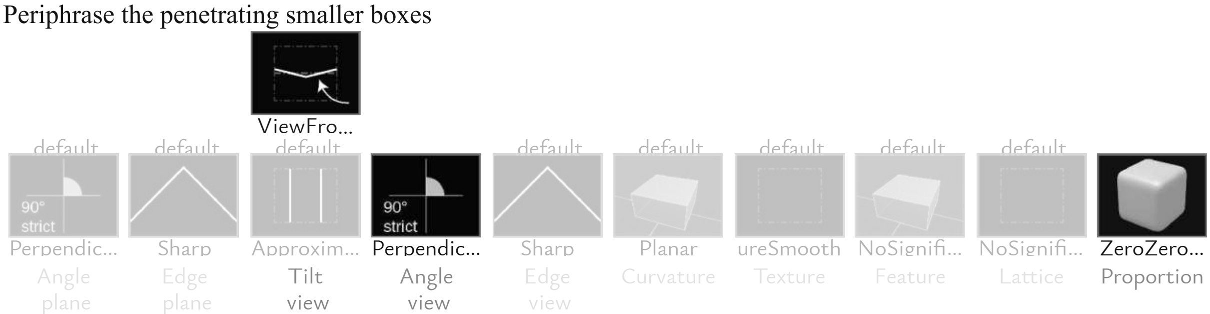
U2 - Expo 2010 Hamburg Urban Pavilion (Shanghai)



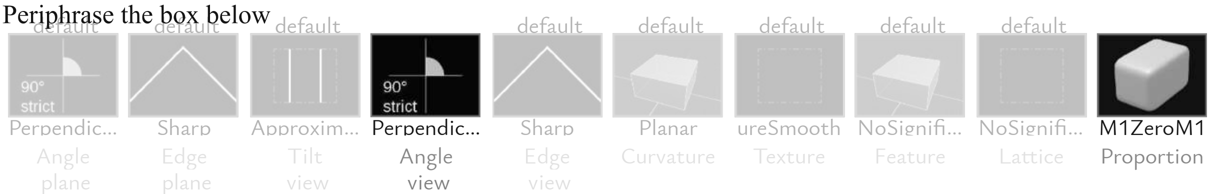
Periphrase main building shape



Periphrase the penetrating smaller boxes



Periphrase the box below



U3 - Expo 1970 Netherlands Pavilion (Osaka)

1. <Flickr_userPetespix75> 4381419661_9e6baae671_o

2. <Flickr_userNyclondonguy> 8012618441_0ac28543b4_b

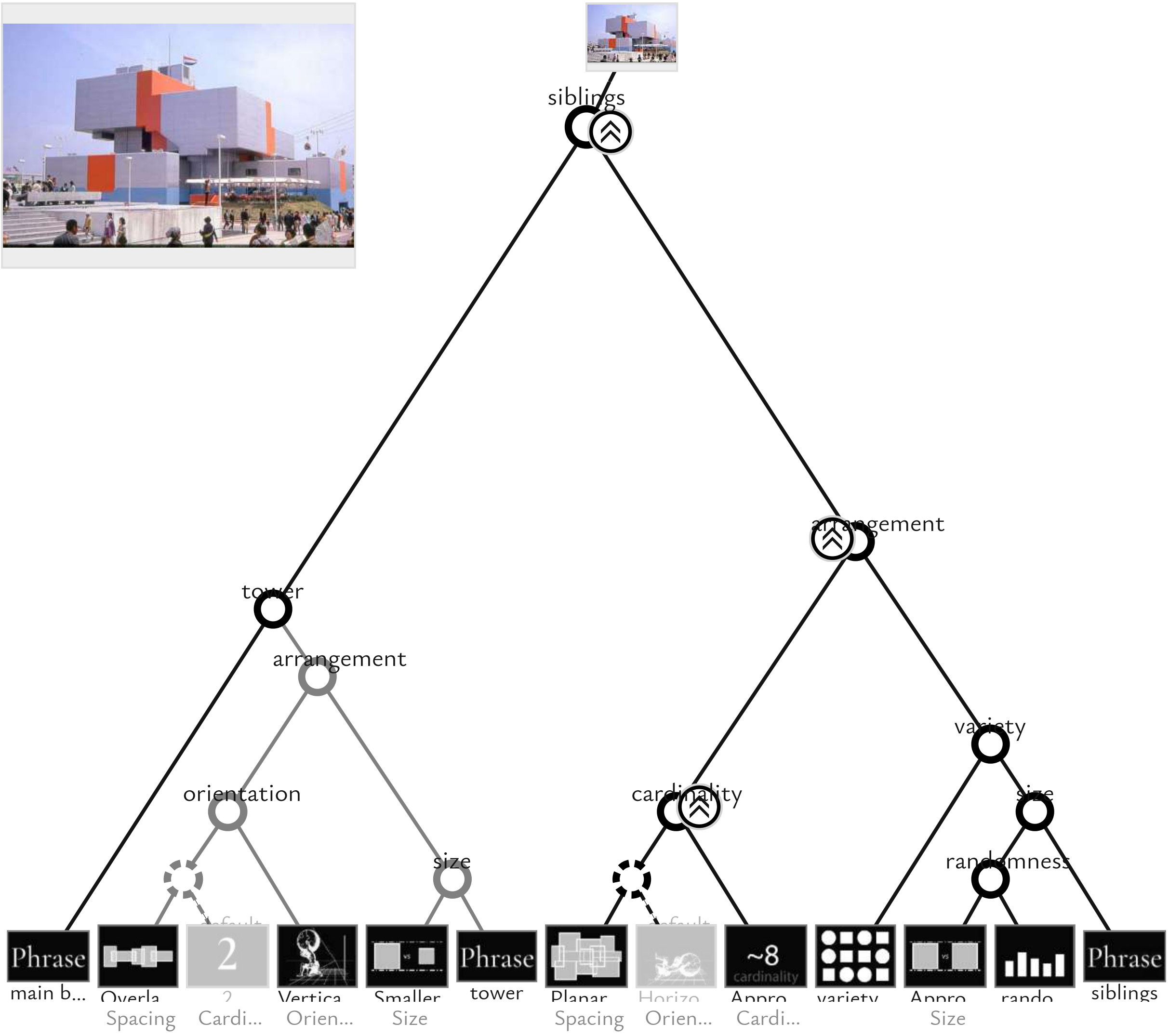
3. <Flickr_userKOota> 5798570851_3ed9424993_o

4. <Flickr_userNyclondonguy> 8012564669_e345f2af42_k

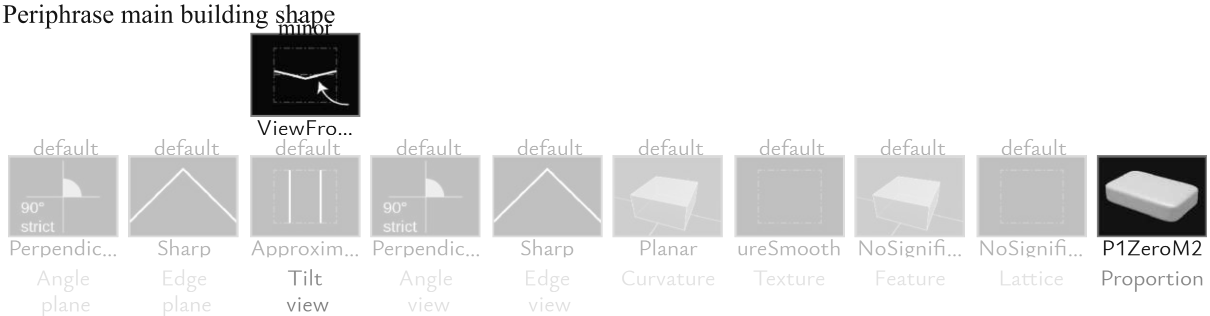
5. <YouTube_userTyokutoku> 5yVvBW4p7z8_1

Group:	U - Penetrate Boxes (Position: 3)	Year, City:	1970 Osaka
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	nl70
Empirical Id:	emp-n-nl70	Brief:	Netherlands (1970)
Internal Ids:	prj3128, rep242, itm194	Full:	Netherlands Pavilion (1970)
Tags:	expo1970/n-pav-nl	Qualified:	(see headline)

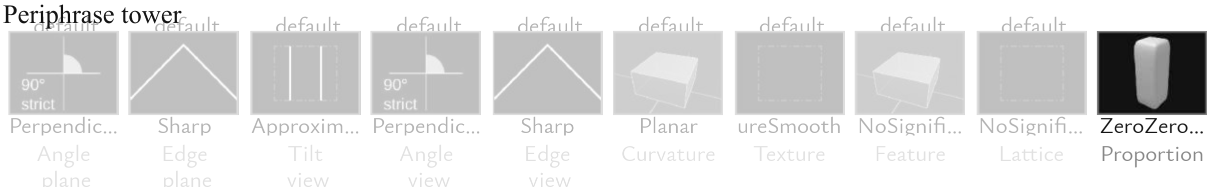
U3 - Expo 1970 Netherlands Pavilion (Osaka)



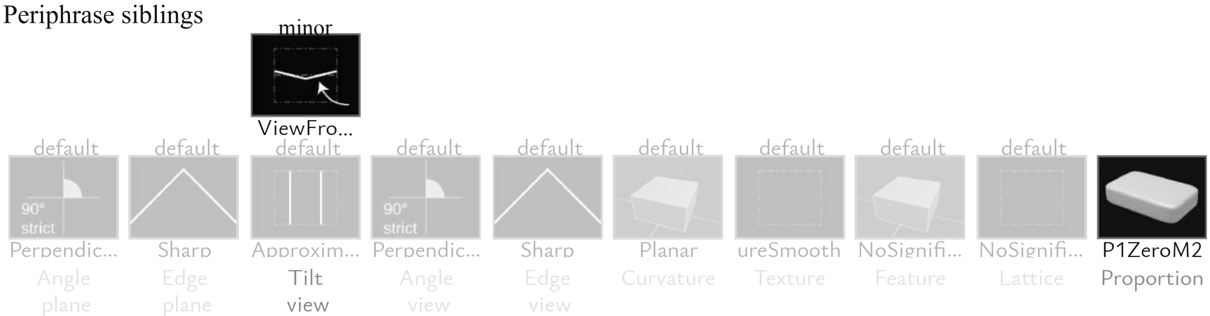
Periphrase main building shape



Periphrase tower



Periphrase siblings



V1 - Expo 1967 Austria Pavilion (Montreal)

1. <ArchivesdemontreallcaAtomOrg> VM94-EX265-138

2. <Expo67NcfCa> 2austria_3aae0fe66c

3. <ArchivesdemontreallcaAtomOrg> VM94-Bd1-046

4. <ArchivesdemontreallcaAtomOrg> VM94-B220-029

5. <ArchivesdemontreallcaAtomOrg> VM94-Bd1-070

6. <ArchivesdemontreallcaAtomOrg> VM94-EX281-014

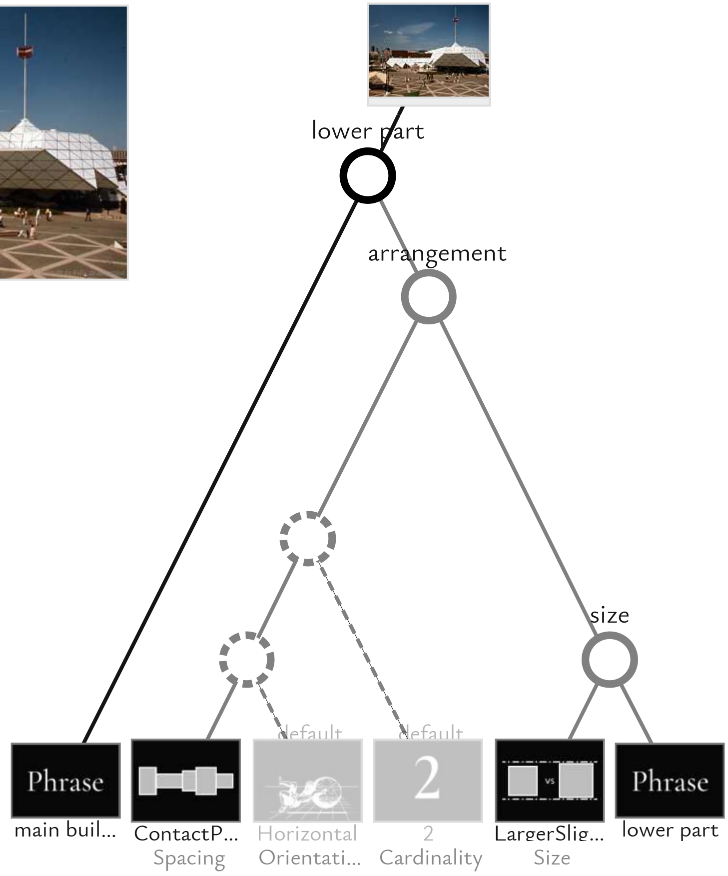
7. <Flickr_userEspressobuzzUploadedByMagstb67> 4278478268_5b08daf5e8_o

8. <Flickr_userMagstb67> 13332928653_98b81833c8_o

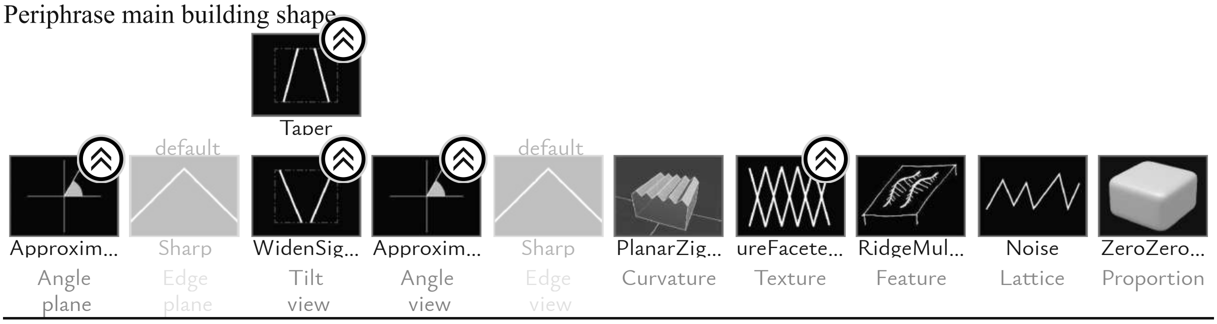
9. <Flickr_userPetespix75> nr01

Group:	V - Geometry (Position: 1)	Year, City:	1967 Montreal
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	at67
Empirical Id:	emp-n-at67	Brief:	Austria (1967)
Internal Ids:	prj2401, rep243, itm242	Full:	Austria Pavilion (1967)
Tags:	expo1967/n-pav-at/nn-austria	Qualified:	(see headline)

V1 - Expo 1967 Austria Pavilion (Montreal)



Periphrase main building shape



Periphrase lower part

V2 - Expo 1970 Italy Pavilion (Osaka)

1. <Flickr_userLizstless> 432849205_ad89edabfb_o

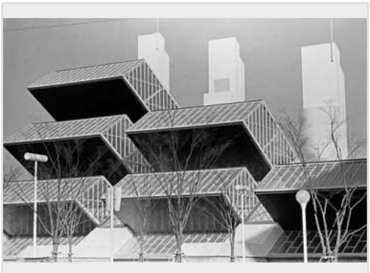
2. <OdasanS48XreaCom> 407

3. <Flickr_userNyclondonguy> 8012458059_149660f118_k

4. <NiftyComSaekiSin> b623italia_xnconverted

5. <Flickr_userKOota> 5799121504_e44c059348_o

6. <AntonraubenweissCom_byWwwArchNusEduSg> italianpav

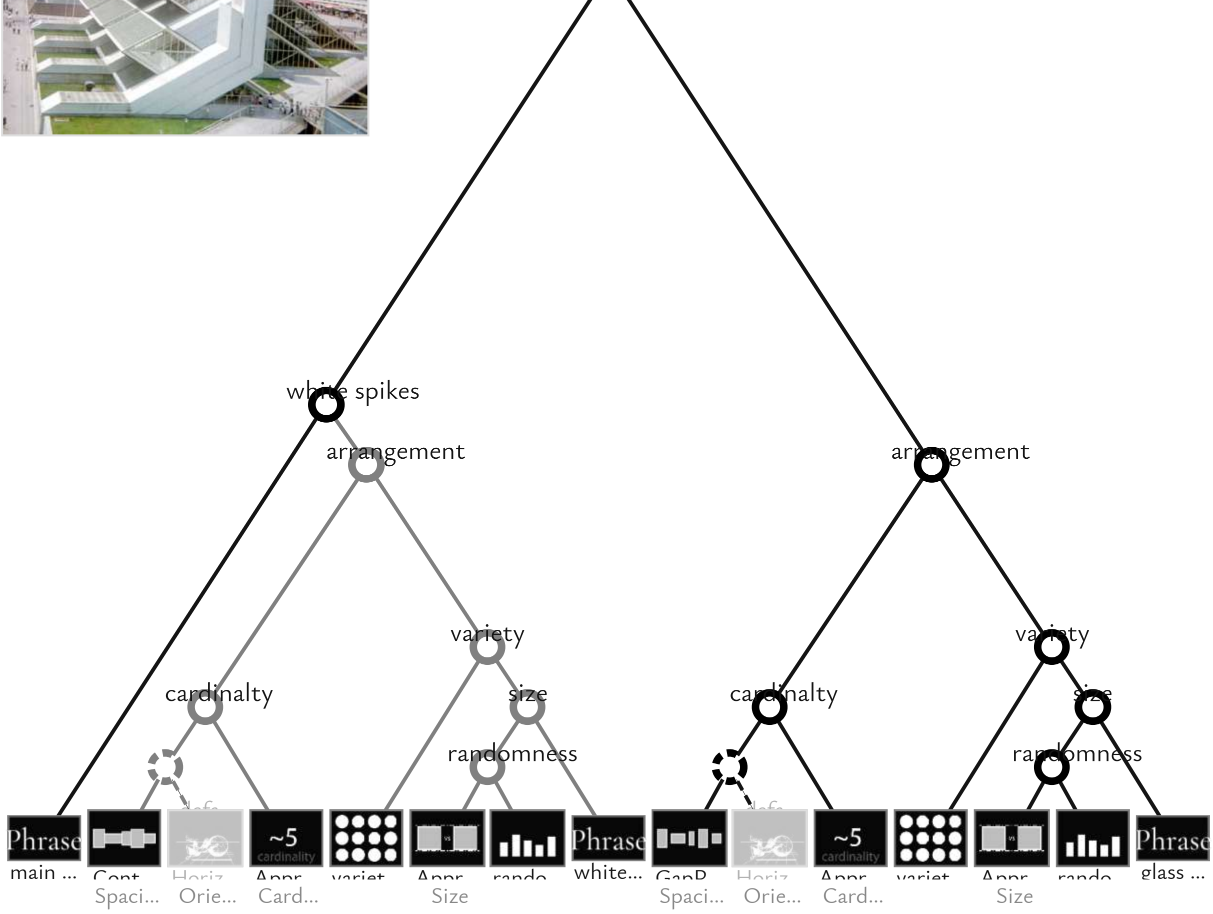


7. <Magnum_byReneBruni> PAR377877

8. <Flickr_userNyclondonguy> 8012634961_47cb6fc1d7_b

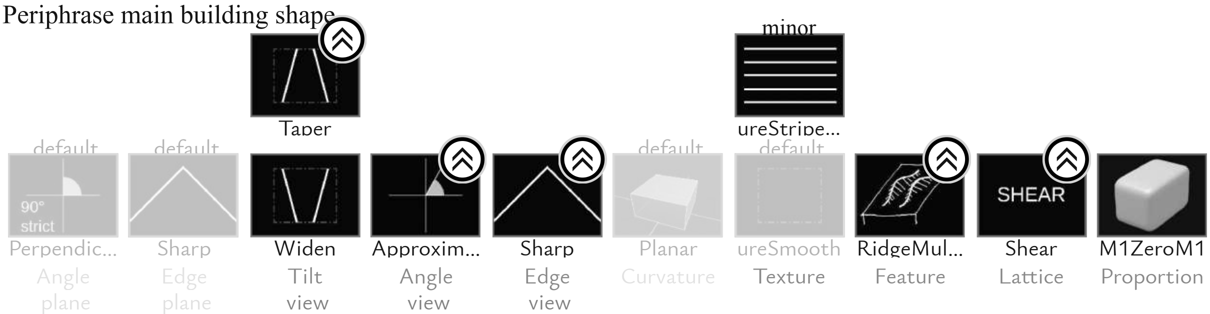
Group:	V - Geometry (Position: 2)	Year, City:	1970 Osaka
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	it70
Empirical Id:	emp-n-it70	Brief:	Italy (1970)
Internal Ids:	prj3120, rep245, itm247	Full:	Italy Pavilion
Tags:	expo1970/n-pav-it	Qualified:	(see headline)

V2 - Expo 1970 Italy Pavilion (Osaka)

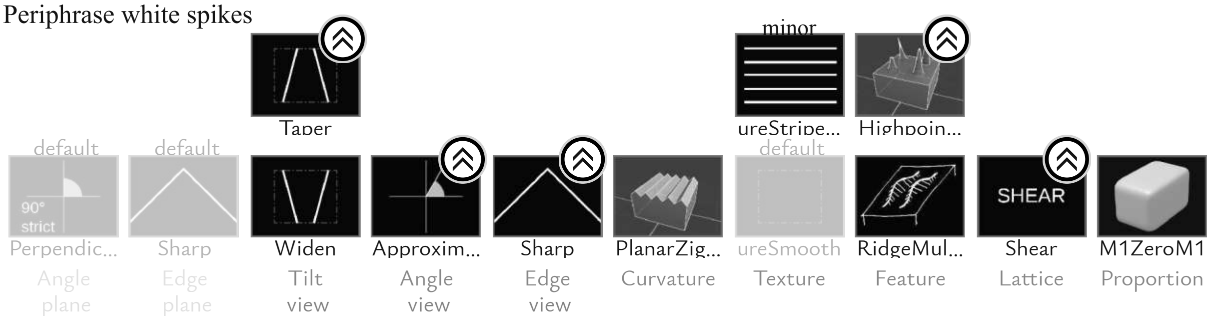


V2 - Expo 1970 Italy Pavilion (Osaka)

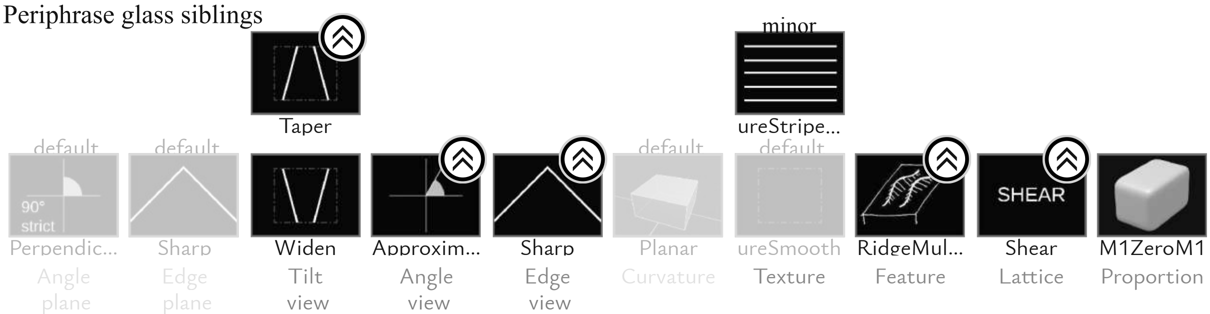
Periphrase main building shape



Periphrase white spikes



Periphrase glass siblings



This page intentionally left blank in print layout

V3 - Expo 1967 Man The Explorer Theme Pav. (Montreal)

1. <ArchivesdemontrealIcaAtomOrg> VM94-B208-021

2. <ArchivesdemontrealIcaAtomOrg> VM94-B220-036

3. <ArchivesdemontrealIcaAtomOrg> VM94-B92-006

4. <Flickr_userBdutfield> 3090530047_399089e356_o

5. <GbphotodidacticalCa> Photo-Expo-67-18-The-Theme-Pavilions

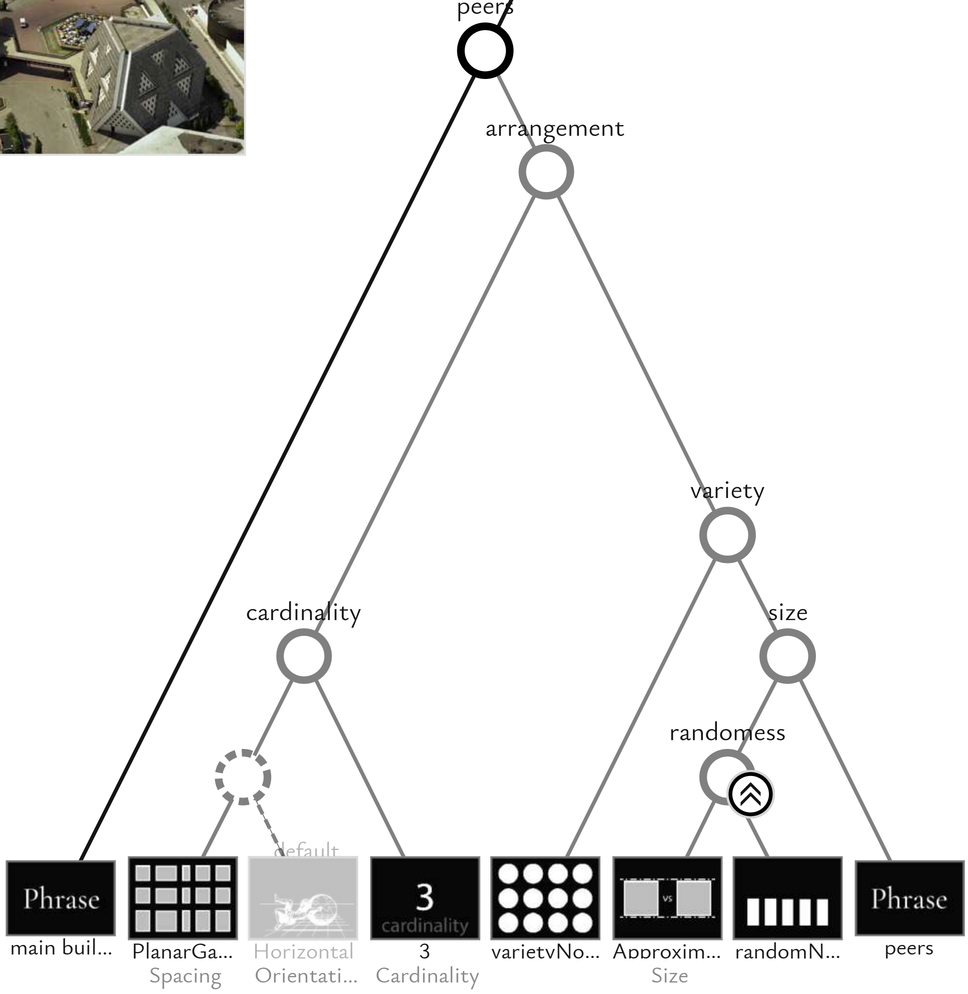
6. <ArchivesdemontrealIcaAtomOrg> VM94-EX136-411

7. <ArchivesdemontrealIcaAtomOrg> VM94-EX136-638

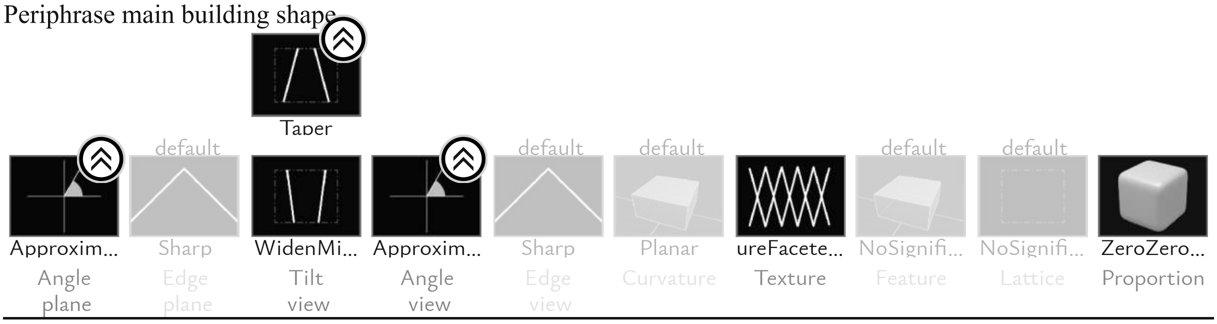
8. <GbphotodidacticalCa> Photo-Expo-67-17-The-Theme-Pavilions

Group:	V - Geometry (Position: 3)	Year, City:	1967 Montreal
Pavilion Type:	Theme Pavilion (t-pav)	Shortest:	exp
Empirical Id:	emp-t-explorer	Brief:	Man The Explorer
Internal Ids:	prj2529, rep244, itm261	Full:	Man The Explorer Theme Pavilion
Tags:	expo1967/t-pav/tn-manTheExplorer	Qualified:	(see headline)

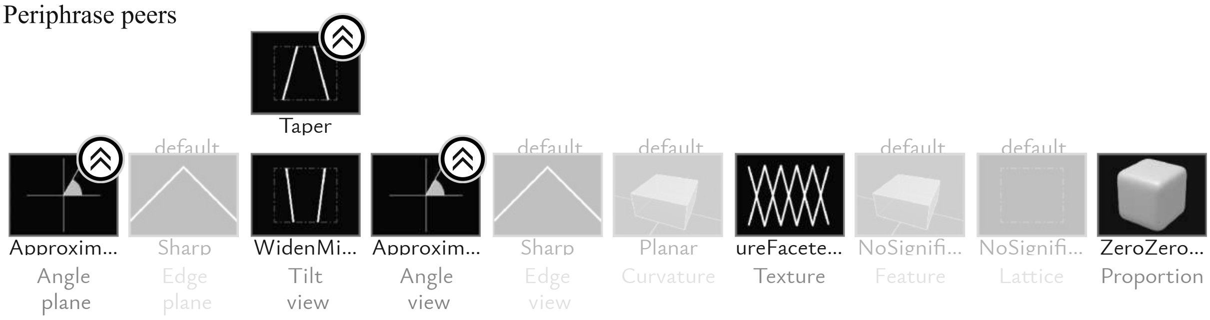
V3 - Expo 1967 Man The Explorer Theme Pav. (Montreal)



Periphrase main building shape



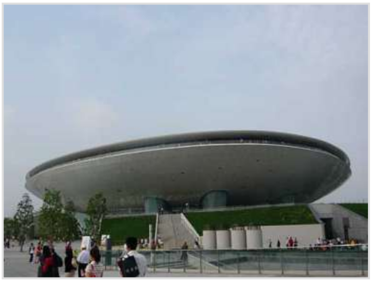
Periphrase peers



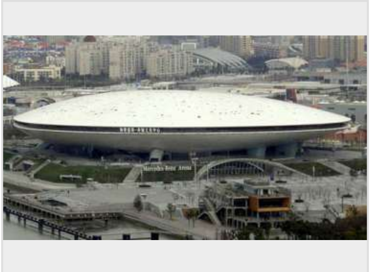
W1 - Expo 2010 Expo Culture Center Host Pav. (Shanghai)

1. <Flickr_userKimon> 463317 1163_a3dcc6b589_o

2. <GoogleMaps>



3. <PJ> 1040653

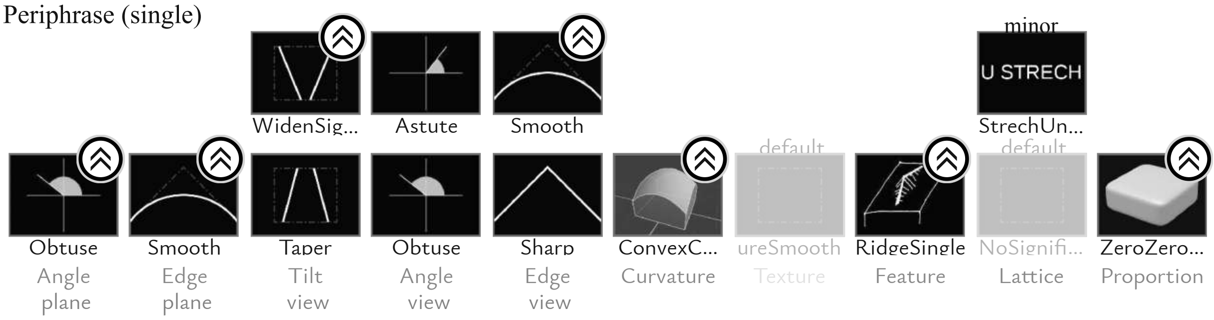


4. <Panoramio_user3962419_ (DuyiHan)> 49651376

5. <Expo2010ShanghaiChinaFr omTheAir> expo0010

Group:	W - Ufo (Position: 1)	Year, City:	2010 Shanghai
Pavilion Type:	Host Building (host)	Shortest:	h-cu
Empirical Id:	emp-host-culture	Brief:	Expo Culture Center
Internal Ids:	prj2003, rep246, itm257	Full:	Expo Culture Center Host Pavilion
Tags:	expo2010/host/hn-expoCultureCenter	Qualified:	(see headline)

Periphrase (single)



W2 - Expo 2010 Singapore Pavilion (Shanghai)

1. <Flickr_userExpomuseum> 4684914512_510197747a_o

2. <Flickr_userWojtekgurak> 5446744378_480ca229ea_o

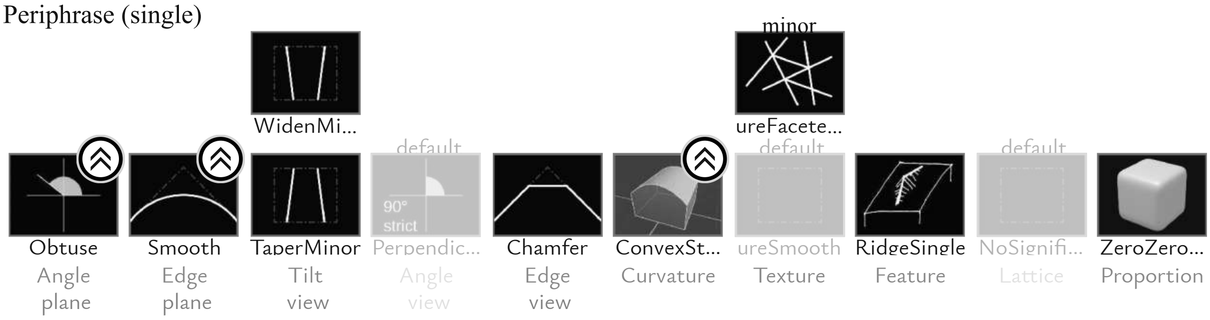
3. <Expo2010ShanghaiChinaFromTheAir> expo0008

4. <Flickr_userChimaybleue> 4735121426_e738c95008_b

5. <BingMaps>

Group:	W - Ufo (Position: 2)	Year, City:	2010 Shanghai
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	sg
Empirical Id:	emp-n-sg	Brief:	Singapore
Internal Ids:	prj2166, rep248, itm239	Full:	Singapore Pavilion
Tags:	expo2010/n-pav-sg/nn-singapore	Qualified:	(see headline)

Periphrase (single)



W3 - Expo 1998 Pav. of the Future Theme Pavilion (Lisboa)


1. <PJ> P1050727


2. <BingMaps> 02

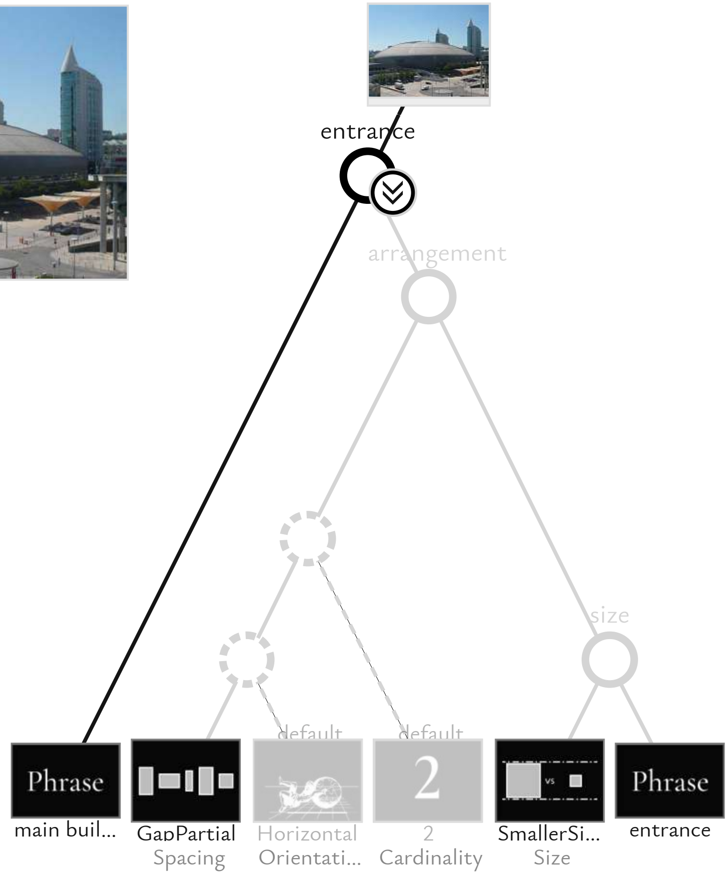

3. <BingMaps> 01

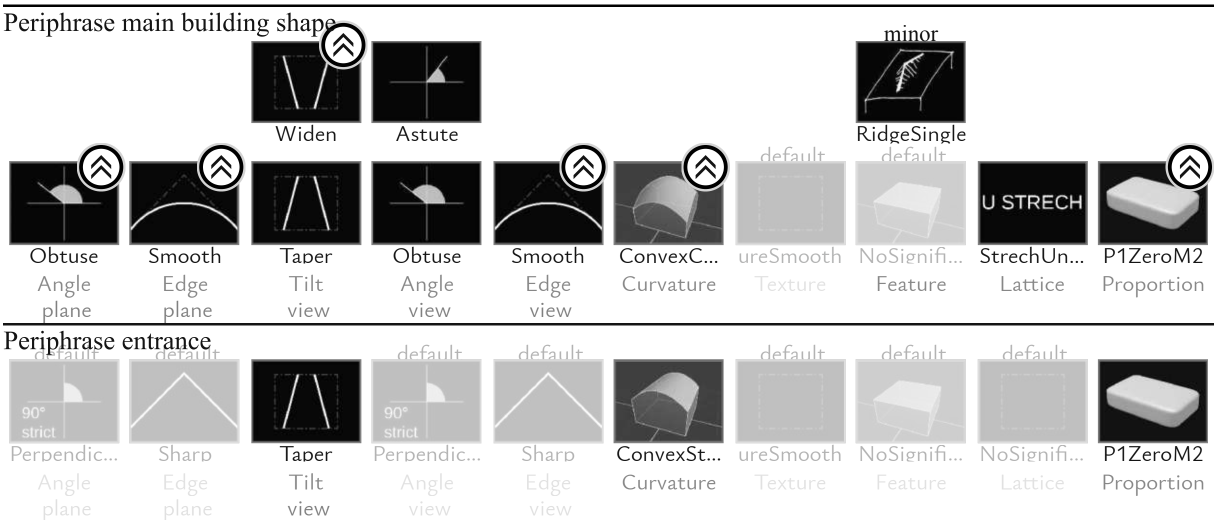

4. <PJ> P1050670


5. <PJ> P1050731

Group:	W - Ufo (Position: 3)	Year, City:	1998 Lisboa
Pavilion Type:	Theme Pavilion (t-pav)	Shortest:	fut
Empirical Id:	emp-t-future	Brief:	Pavilion Of The Future
Internal Ids:	prj2731, rep247, itm255	Full:	Pav. of the Future Theme Pavilion
Tags:	expo1998/t-pav/tn-PavilionOfTheFuture	Qualified:	(see headline)

W3 - Expo 1998 Pav. of the Future Theme Pavilion (Lisboa)





X1 - Expo 2010 Innovative Tours Theme Pavilion (Shanghai)

1. <Expo2010ShanghaiChinaFromTheAir> expo0036b

2. <BingMaps>

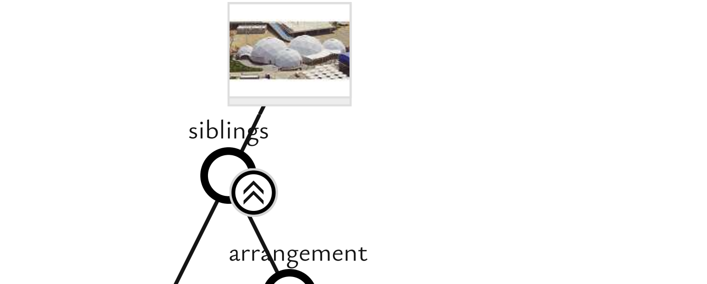
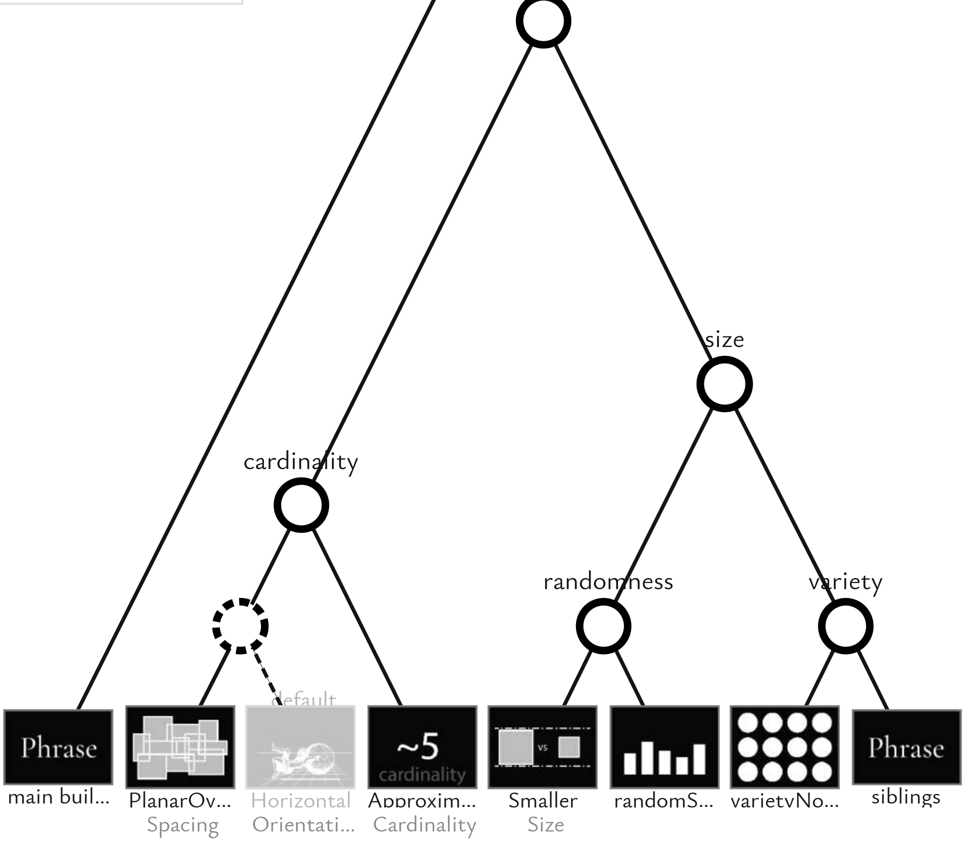
3. <Panoramio_user604433_(utf8)> 37500380

4. <Panoramio_user604433_(utf8)> 37500459

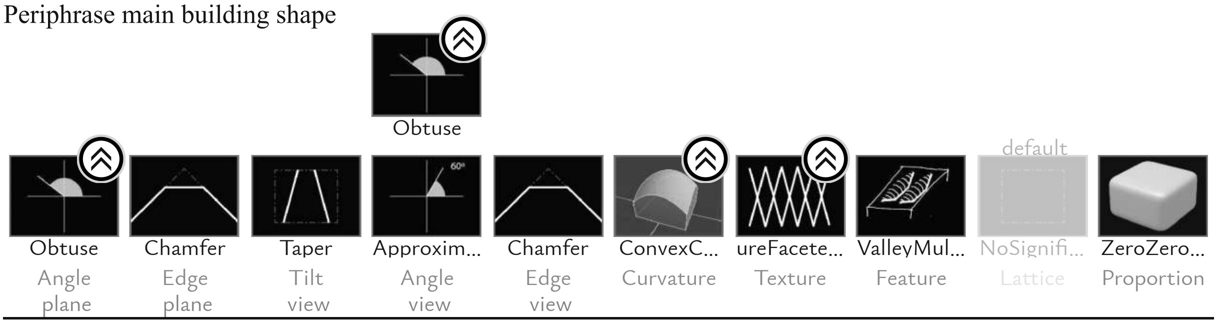
5. <Flickr_userExpomuseum> 4792215561_30efc7f93b_o

Group:	X - Bubbles (Position: 1)	Year, City:	2010 Shanghai
Pavilion Type:	Theme Pavilion (t-pav)	Shortest:	tour
Empirical Id:	emp-t-tours	Brief:	Innovative Tours
Internal Ids:	prj2229, rep249, itm179	Full:	Innovative Tours Theme Pavilion
Tags:	expo2010/t-pav/tn-innovativeTours	Qualified:	(see headline)

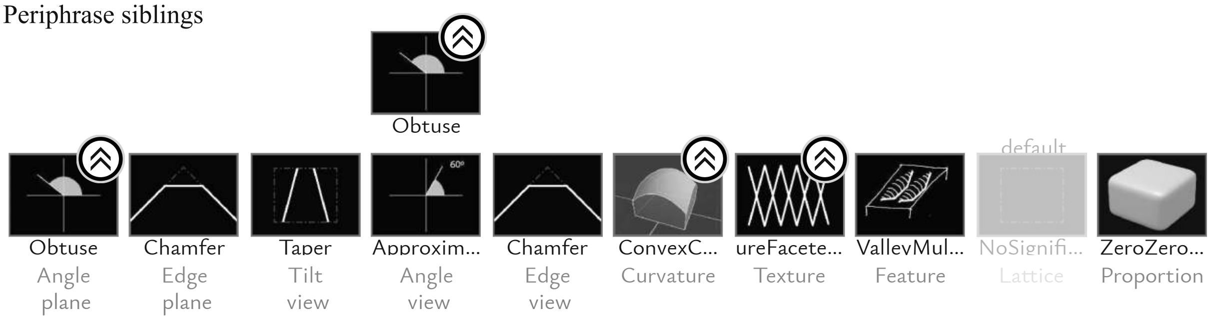
X1 - Expo 2010 Innovative Tours Theme Pavilion (Shanghai)

Periphrase main building shape



Periphrase siblings



X2 - Expo 1967 Brewers Pavilion (Montreal)


1. <ArchivesdemontrealIcaAtomOrg> VM94-B220-064


2. <ArchivesdemontrealIcaAtomOrg> VM94-EX67-019

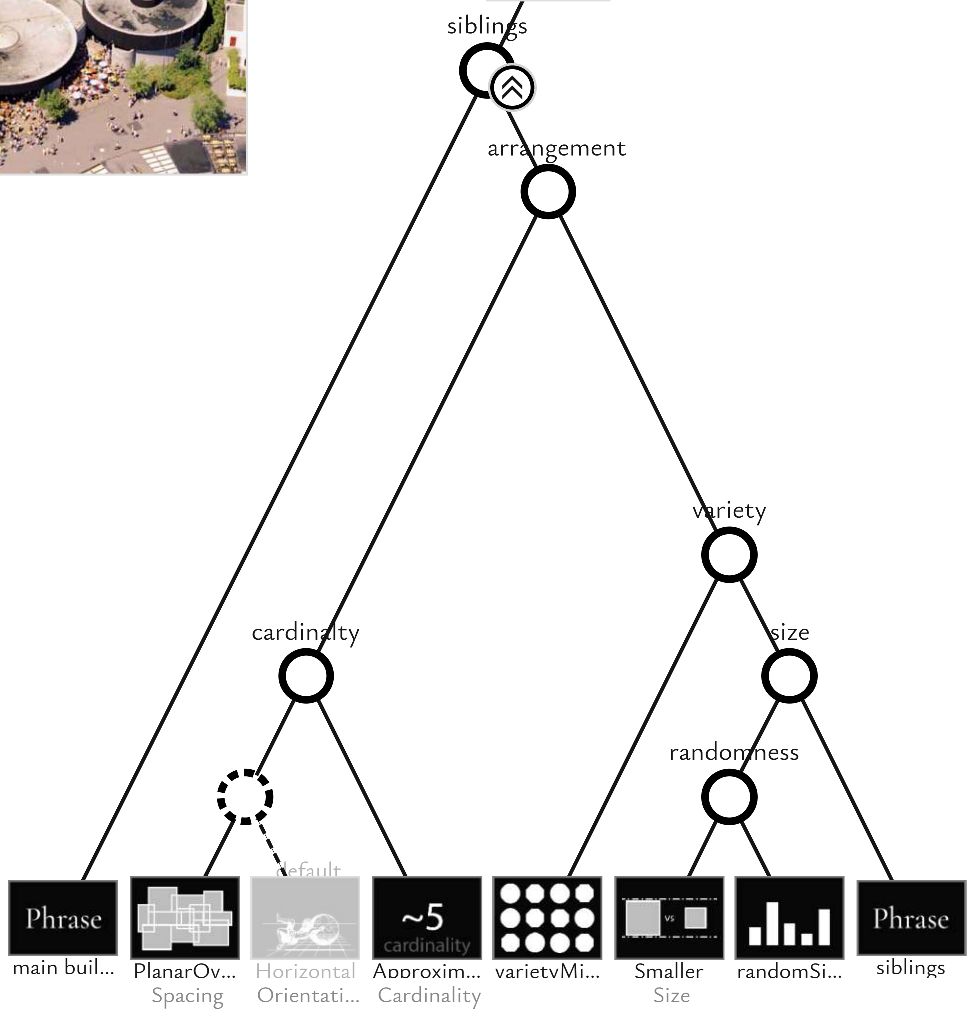

3. <ArchivesdemontrealIcaAtomOrg> VM94-EX281-060


4. <Flickr_userMagstb67> 2717449081_1b1653aa6a_o

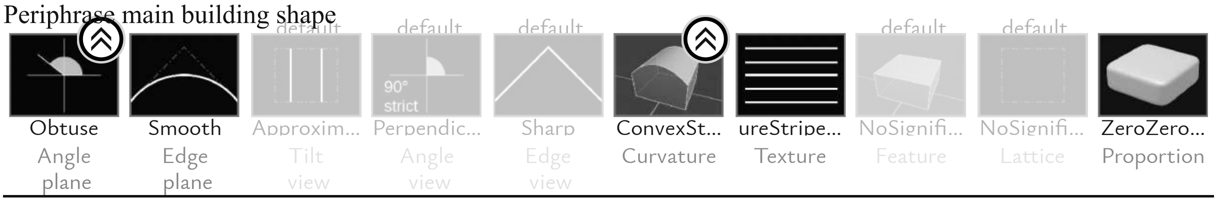

5. <Flickr_userErezUploadedByMagstb67> 2718333802_4a24cc77ec_o

Group:	X - Bubbles (Position: 2)	Year, City:	1967 Montreal
Pavilion Type:	Corporate Pavilion (c-pav)	Shortest:	brew
Empirical Id:	emp-c-brewers	Brief:	Brewers
Internal Ids:	prj2562, rep251, itm181	Full:	Brewers Pavilion
Tags:	expo1967/c-pav/cn-brewersPav	Qualified:	(see headline)

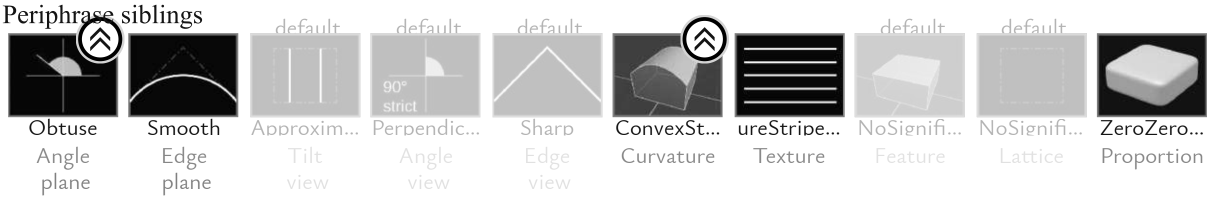
X2 - Expo 1967 Brewers Pavilion (Montreal)



Periphrase main building shape



Periphrase siblings

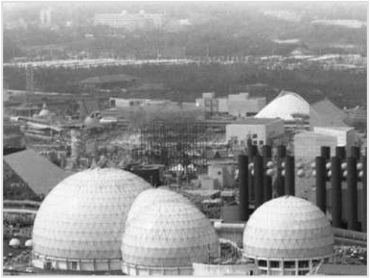


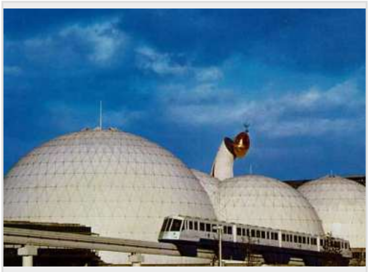
X3 - Expo 1970 France Pavilion (Osaka)


1. <Life_byCarlMydans> 06


2. <Sonynaviblogsonetnejp> ds c03496-957f4

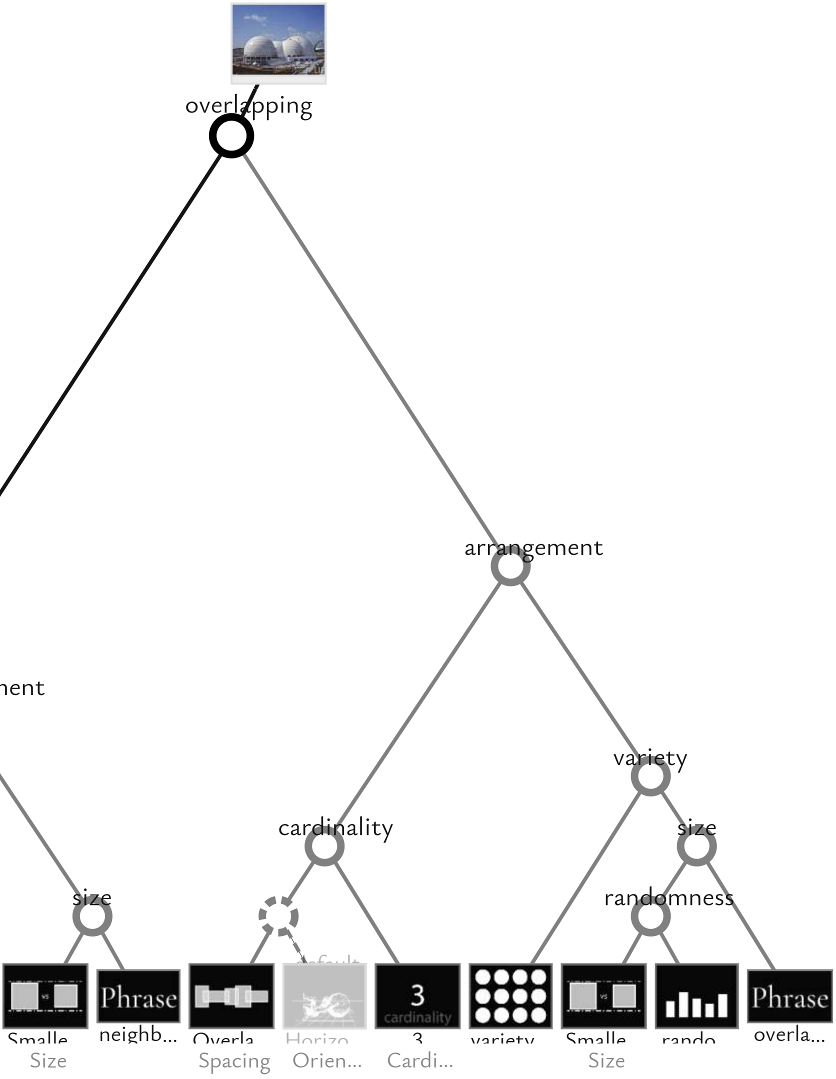

3. <Life_byCarlMydans> 8b19 84b37ea6a36a_large


4. <NiftyComSaekiSin> tenbou 3-2


5. <Flickr_userKOota> 579912 5190_cf49e2ce9a_o

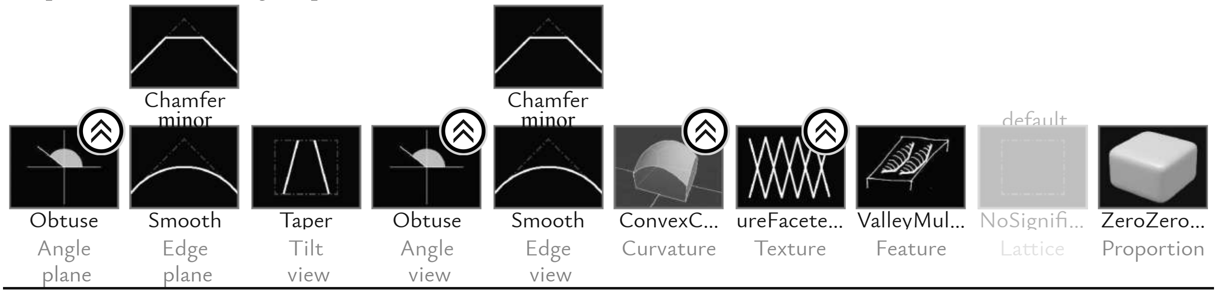
Group:	X - Bubbles (Position: 3)	Year, City:	1970 Osaka
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	fr70
Empirical Id:	emp-n-fr70	Brief:	France (1970)
Internal Ids:	prj3117, rep250, itm180	Full:	France Pavilion (1970)
Tags:	expo1970/n-pav-fr	Qualified:	(see headline)

X3 - Expo 1970 France Pavilion (Osaka)

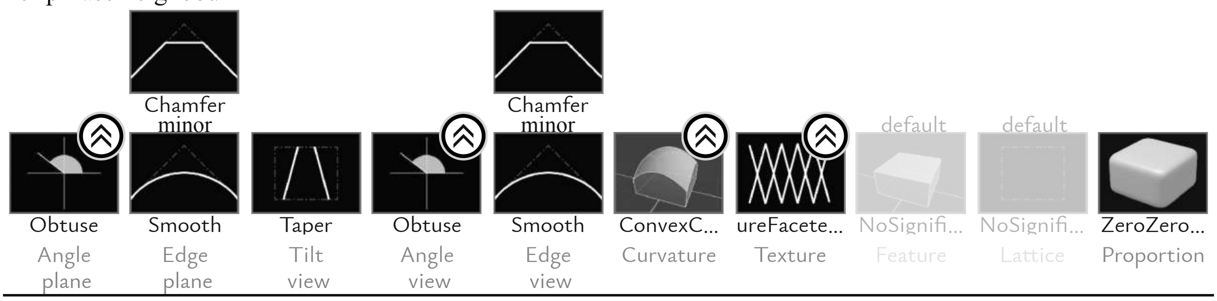


X3 - Expo 1970 France Pavilion (Osaka)

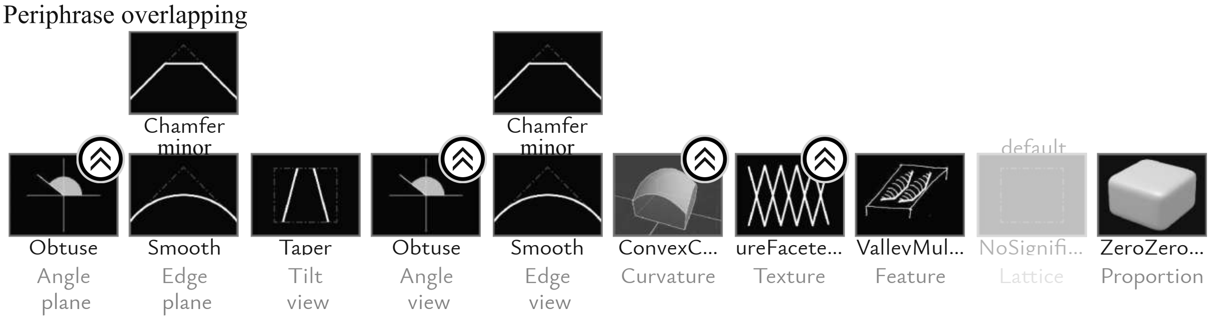
Periphrase main building shape



Periphrase neighbour



Periphrase overlapping



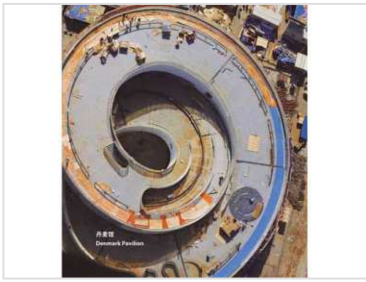
Y1 - Expo 2010 Denmark Pavilion (Shanghai)

1. <Flickr_userWojtekgurak> 5513020721_5e3d2b4dfd_o

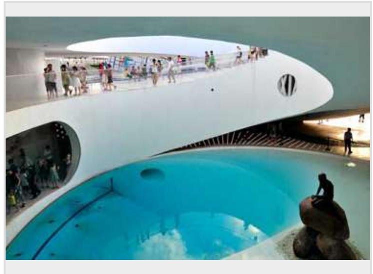
2. <Flickr_userWojtekgurak> 5515689991_3061cf3dcd_o

3. <Flickr_userSnapshotunlimited> 4609013022_57f3690e74_b

4. <Flickr_userFrankschacht> 4848890307_a780f0f1f1_b



5. <Expo2010ShanghaiChinaFromTheAir> expo0034



6. <Flickr_userCesarCorona> 4811903872_412c360ee9_o

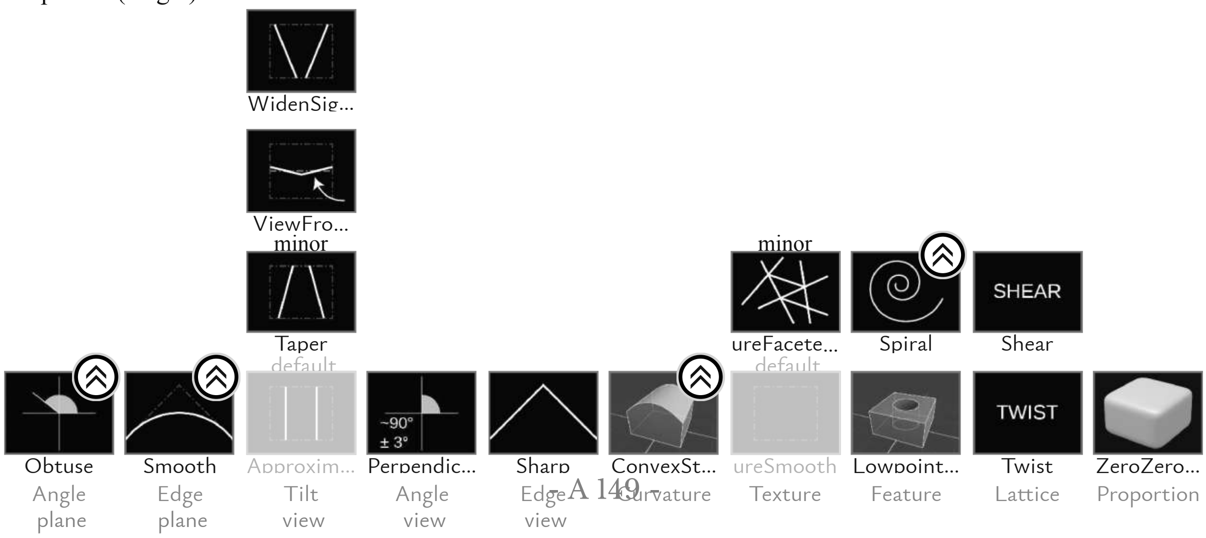
7. <BingMaps>

8. <11tecomBlog163Com_byAFP> Shanghai_Expo--6--600x400

9. <PJ> 1040369

Group:	Y - Spiral (Position: 1)	Year, City:	2010 Shanghai
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	dk
Empirical Id:	emp-n-dk	Brief:	Denmark
Internal Ids:	prj2117, rep252, itm186	Full:	Denmark Pavilion
Tags:	expo2010/n-pav-dk/nn-denmark	Qualified:	(see headline)

Periphrase (single)



Y2 - Expo 2010 General Motors Corporate Pav. (Shanghai)


1. <Expo2010ShanghaiChinaFromTheAir> expo0042c

2. <Panoramio_user2481456_(JunjunGuo)> 40835814


3. <BingMaps>

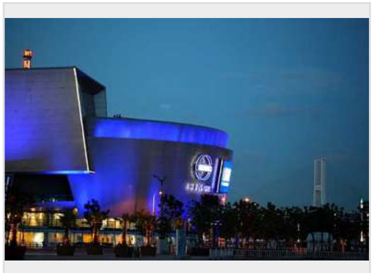

4. <Flickr_userExpomuseum> 4782677724_61941f688e_o


5. <Flickr_userExpomuseum> 4713960901_da4074fb2b_o


6. <PJ> 1040403

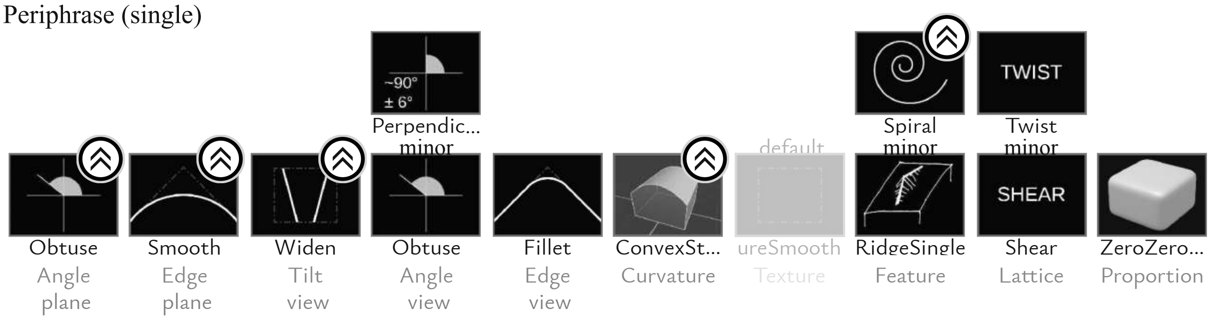

7. <Expo2010ShanghaiChinaFromTheAir> 141

8. <Flickr_userExpomuseum> 4782604510_41e1707dd5_o

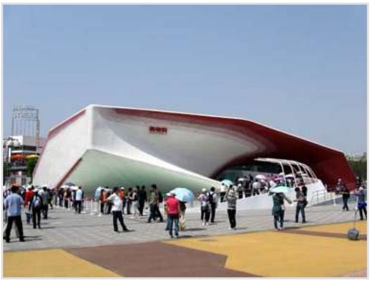

9. <Flickr_userLzwwWw> 5136930514_30bdb7e6d6_o

Group:	Y - Spiral (Position: 2)	Year, City:	2010 Shanghai
Pavilion Type:	Corporate Pavilion (c-pav)	Shortest:	gm
Empirical Id:	emp-c-gm	Brief:	General Motors
Internal Ids:	prj2267, rep253, itm260	Full:	General Motors Corporate Pavilion
Tags:	expo2010/c-pav/cn-gm	Qualified:	(see headline)

Periphrase (single)



Y3 - Expo 2010 Austria Pavilion (Shanghai)

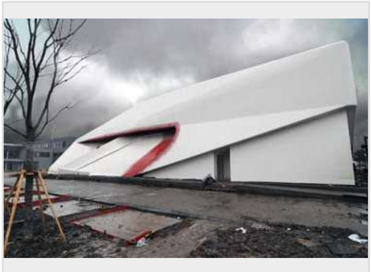

1. <Panoramio_userXiemingjun3616879> 35039246


2. <Expo2010ShanghaiChinaFromTheAir> expo0020b

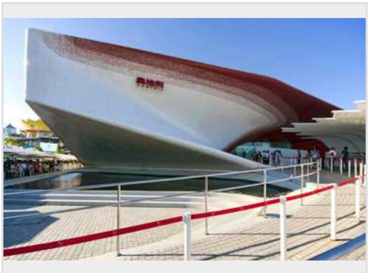

3. <GoogleMaps>


4. <ArchdailyCom_austriaPav> 1269444446-6a00cdf7e45ea8094f0123ddf547b4860c


5. <ArchdailyCom_austriaPav> 1269444388-6a00cdf7e45ea8094f0123f19f144f860f


6. <ArchdailyCom_austriaPav> 1269444365-6a00cdf7e45ea8094f01240bb2ad30860e

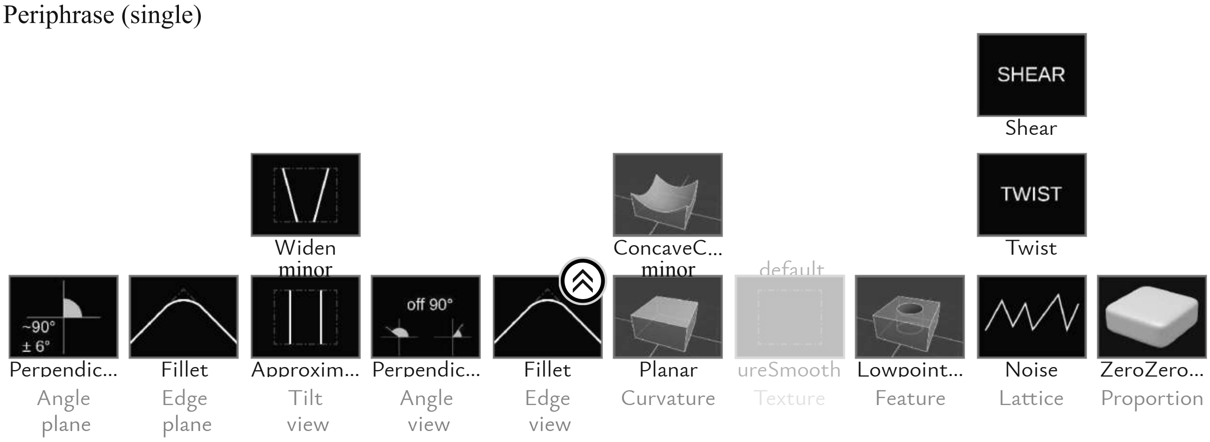

7. <PJ> 1040313


8. <Flickr_userWojtekgurak> 5420205338_c64a18b575_o

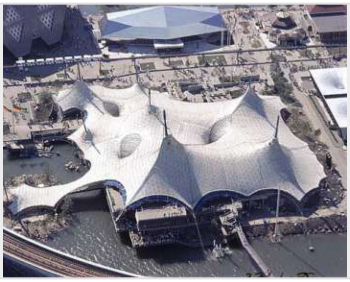

9. <Expo2010ShanghaiChinaFromTheAir> 161

Group:	Y - Spiral (Position: 3)	Year, City:	2010 Shanghai
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	at10
Empirical Id:	emp-n-at10	Brief:	Austria (2010)
Internal Ids:	prj2103, rep259, itm183	Full:	Austria Pavilion (2010)
Tags:	expo2010/n-pav-at/nn-austria	Qualified:	(see headline)

Periphrase (single)

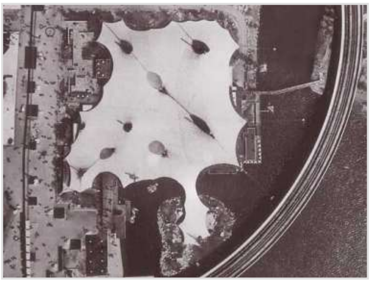


Z1 - Expo 1967 Germany Pavilion (Montreal)


1. <CollectionscanadaGcCa> e 000990839


2. <Flickr_userMagstb67> 133 32791905_073afb21fc_o


3. <Flickr_userMagstb67> 133 32936303_5a88de7c26_o


4. <Exponiert> pic167page232


5. <ArchivesdemontrealIcaAtomOrg> VM94-EX281-037


6. <Flickr_userBdutfield> 3090 612175_a9fe5821ba_o


7. <AlamedainfoCom> Expo_67_The_Pavilion_of_Germany_Montreal_Canada

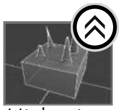

8. <Expo67NcfCa> german_na e000990939

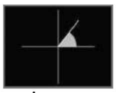

9. <Flickr_userErezUploadedByMagstb67> 2717451843_702fe12ec3_o

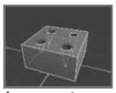
Group:	Z - Anticlastic (Position: 1)	Year, City:	1967 Montreal
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	de67
Empirical Id:	emp-n-de67	Brief:	Germany (1967)
Internal Ids:	prj2407, rep255, itm201	Full:	Germany Pavilion (1967)
Tags:	expo1967/n-pav-de/nn-germany	Qualified:	(see headline)

Periphrase (single)

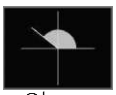
Perpendic...

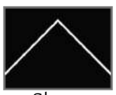

Highpoin...

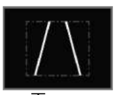

Astute


Lowpoint...

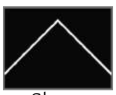

Noise

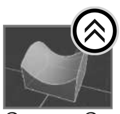

Obtuse Angle plane

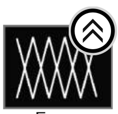

Sharp Edge plane

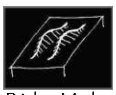

Taper Tilt view

Perpendic... Angle view


Sharp Edge view


ConcaveC... Curvature


ureFacete... Texture


RidgeMul... Feature

StrechUn... Lattice


ZeroZero... Proportion

Z2 - Expo 2010 Norway Pavilion (Shanghai)


1. <Flickr_userWojtekgurak> 5463400364_08360ee750_o


2. <Panoramio_user604433_(吉易)> 37109502


3. <Panoramio_user710947_(Dxinwei)> 34813851


4. <KnippershelbigCom> 13755-picture


5. <GoogleMaps>


6. <Flickr_userKimon> 4690061310_548aa6b0e3_o

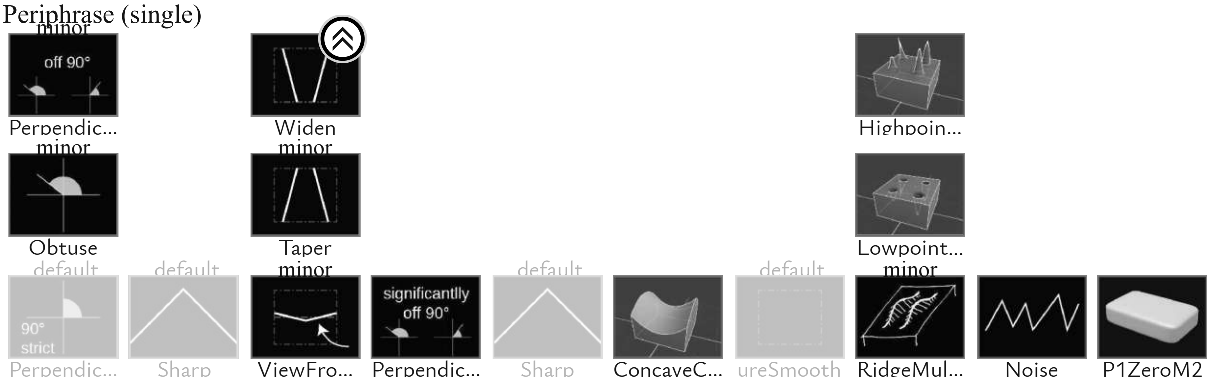

7. <HelenhardNo> Expo-John_E_Kroll-02-website


8. <Flickr_userChazhutton> 4553904399_c07e100c71_o


9. <Flickr_userWojtekgurak> 5463400198_d0d0b7fb48_o

Group:	Z - Anticlastic (Position: 2)	Year, City:	2010 Shanghai
Pavilion Type:	Nation Pavilion (n-pav)	Shortest:	no
Empirical Id:	emp-n-no	Brief:	Norway
Internal Ids:	prj2151, rep260, itm211	Full:	Norway Pavilion
Tags:	expo2010/n-pav-no/nn-norway	Qualified:	(see headline)

Periphrase (single)



Angle plane | Edge plane | Tilt view | Angle view | Edge view | Curvature | Texture | Feature | Lattice | Proportion

Z3 - Expo 1970 Telecommunication Corporate Pav. (Osaka)

1. <Life_byCarlMydans> 09

2. <UNSW_LSRU_Archive> J P-003_0006

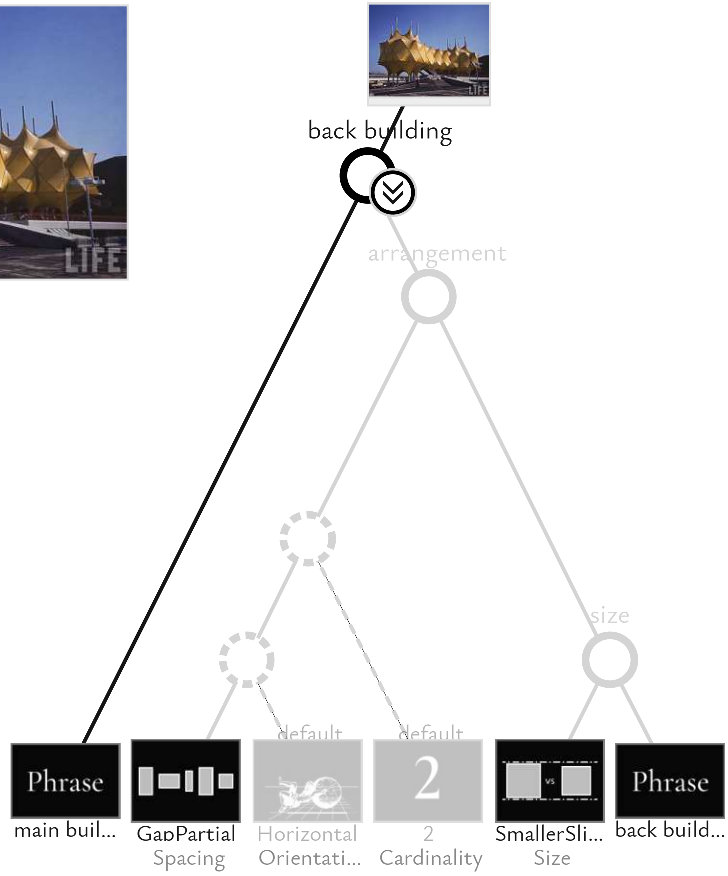
3. <WorldsfaircommunityOrg_byBillCotter> unknown-1

4. <UNSW_LSRU_Archive> J P-003_0005

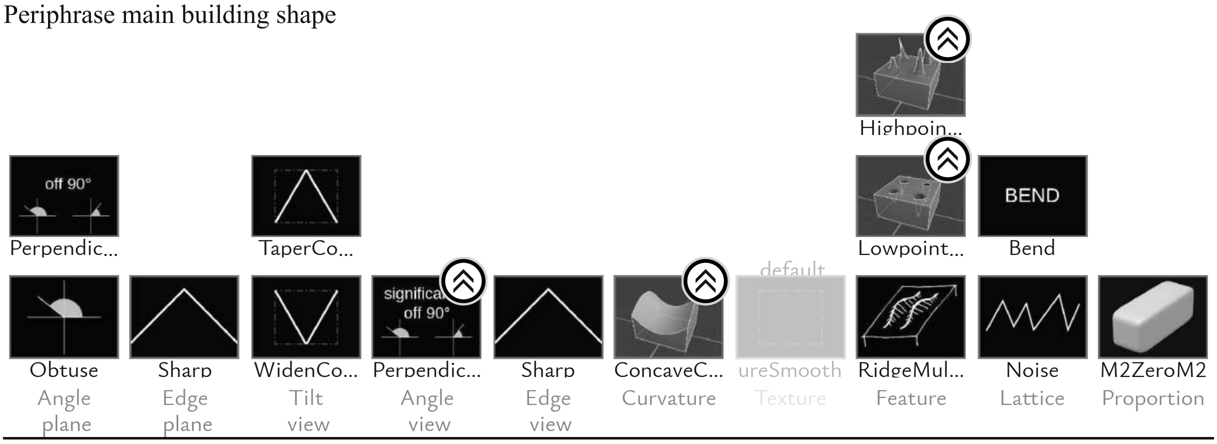
5. <Sonynaviblogsonetnejp> ds c03497-a4dfb

Group:	Z - Anticlastic (Position: 3)	Year, City:	1970 Osaka
Pavilion Type:	Corporate Pavilion (c-pav)	Shortest:	tele
Empirical Id:	emp-c-tele	Brief:	Telecommunication
Internal Ids:	prj3261, rep256, itm253	Full:	Telecommunication Corporate Pavilion
Tags:	expo1970/c-pav/cn-telecommunication	Qualified:	(see headline)

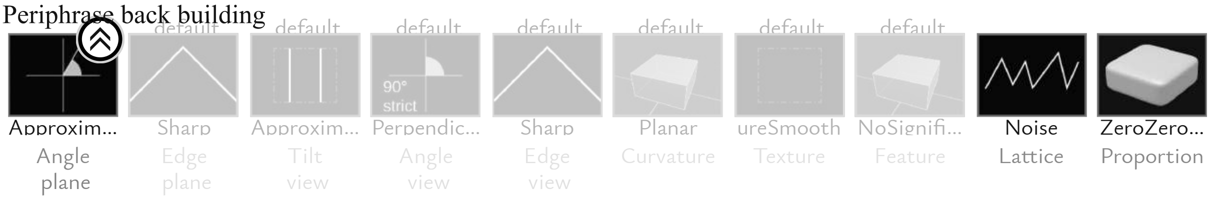
Z3 - Expo 1970 Telecommunication Corporate Pav. (Osaka)



Periphrase main building shape



Periphrase back building



Origins of Photographs

This research makes use of many photographs to discuss Building Shape Classification. This research is based on the academic fair use of the photographs. Care have been taken to reference the original sources. I like to apologise for any missed references or mistakes which might be caused by the sheer volume of the photographs.

Angle brackets like “<ArchivesdemontrealIcaAtomOrg>” are dereferenced further below. Light grey number in th previous pages like “VM94-EX265-133” should help to uniquely identify the photograph from a bigger collection. For Flickr sourced photographs the first part of the identifier is the part of the URL. For instance “7766428922_144da4f956_b” can be accessed as: https://www.flickr.com/photos/hollywoodplace/7766428922

To further help associate the origins to the previous pages, the list contains “occurences”. For example “A2#7” references to the project with the abbreviation “A2” and then the 7th photograph.

Most photographs of pavilions have been accessed in the summer of 201., When a specific date could not be recreated, the more general date “2014” is supplied.

1. **<11tecomBlog163Com_byAFP>** (group:Web) AFP
   http://www.blog.163.com, unavailable, accessed 2014
   occurences: D6#7, F2#6, Y1#8
2. **<24621953AtlebryInfo_byTetsuo>** (group:Web) Tetsuo
   https://24621953.at.webry.info/201112/article_2.html accessed 2014
   occurences: G7#1
3. **<AlamedainfoCom>** (group:Web) alamedainfo.com
   https://alamedainfo.com/Expo_67_Montreal.htm unavailable, accessed 2014
   occurences: G1#9, S3#1, Z1#7
4. **<AntonraubenweissCom_byWwwArchNusEduSg>** (group:Web) Anton Rauben Weiss
   http://www.antonraubenweiss.com/expo/images6.html accessed 2014
   occurences: V2#6
5. **<ArchdailyCom_austriaPav>** (group:Web) Sebastian Jordana
   https://www.archdaily.com/53807/austrian-pavilion-for-shanghai-expo-update published 24 Mar 2010, accessed 2014
   occurences: Y3#4, Y3#5, Y3#6
6. **<ArchdailyCom_philipsPav>** (group:Web)
   https://www.archdaily.com/157658/ad-classics-expo-58-philips-pavilion-le-corbusier-and-iannis-xenakis accessed April 13, 2014
   occurences: B7#1, B7#2, B7#6
7. **<ArchitectureExpo2000Hannover>** (group:BookScan) Expo, 2000. Architektur : Expo 2000 Hannover ; [die Weltausstellung in Deutschland 1. Juni - 31. Oktober 2000]. Ostfildern: Hatje Cantz, 2000.
   occurences: F3#2, H7#5, G3#2
8. **<ArchivesdemontrealIcaAtomOrg>** (group:Archive) Archives de la Ville de Montréal
   Attribution-NonCommercial-ShareAlike 2.5 Canada (CC BY-NC-SA 2.5 CA)
   https://archivesdemontreal.ica-atom.org accessed 2014
   occurences: A3#1, A3#2, A3#4, B2#4, B2#5, B2#7, B2#8, C3#1, C3#2, C3#3, C3#4, C3#5, C3#6, C3#9, D1#8, D2#5, D3#2, D3#5, D3#6, E1#1, E1#4, E3#4, E6#1, E6#3, E6#4, G1#2, G5#4, S3#5, U1#2, U1#3, U1#4, U1#5, V1#1, V1#3, V1#4, V1#5, V1#6, V3#1, V3#2, V3#3, V3#6, V3#7, X2#1, X2#2, X2#3, Z1#5
9. **<AssociatedPress>** (group:Web) Associated Press
   https://www.apimages.com/metadata/Index/Watchf-AP-I-JPN-APHS400974-Aerial-view-of-Expo-70/050ca8ff3c8e42d0adcd4b65272d72fb/202/0, 7003121212, created March 12, 1970 accessed 2014
   occurences: B1#6
10. **<AstudejaoublieBlogspotFr_byFukudaCard>** (group:Web) Osaka - Japon - Cartes postales de l'Expo 70
    http://astudejaoublie.blogspot.com/2012_07_01_archive.html accessed April 13, 2014
    occurences: B1#3, E5#3, F7#1, G7#5
11. **<BingMaps>** (group:BingMaps) Microsoft Corporation, “Satellite Images From Shanghai World Exposition Site”, accessed 2014-11-09, (c) 2014 Nokia, (c) 2014 DigitalGlobe, (c) BLOM, (c) Microsoft Corporation
    the original screenshots are cropped for the research purpose
    occurences: A1#2, A2#8, A4#2, A5#4, A6#4, A7#2, C1#4, C2#4, C4#5, C5#6, C6#4, C7#4, D4#4, E2#4, E4#3, E7#8, F5#8, H1#4, H2#9, H5#2, H6#2, H6#5, G4#4, G6#2, G6#3, T2#6, U2#4, W2#5, W3#2, W3#3, X1#2, Y1#7, Y2#3
12. **<Bobp31HomesteadCom_byBobProcter>** (group:Web) Bob Procter
    https://bobp31.homestead.com unavailable, accessed 2014
    occurences: D7#2

13. **<CollectionscanadaGcCa>** (group:Archive) Library and Archives Canada
https://collectionscanada.gc.ca
https://www.bac-lac.gc.ca/eng accessed 2014
occurences: B2#1, B2#3, D1#2, D1#6, D1#7, D2#1, D2#2, D2#3, D3#4, E3#3, E6#5, G1#3, G1#5, S3#2, S3#3, Z1#1

14. **<Expo2000De>** (group:Web)
https://expo2000.de accessed 2014
occurences: F3#4

15. **<Expo2010ShanghaiChinaFromTheAir>** (group:BookScan) Er, Dongqiang. Expo 2010: Shanghai China from the Air. Hong Kong: Old China Hand Press, 2010.
occurences: A1#1, A2#9, A4#1, A5#1, A5#5, A7#1, B4#4, B5#1, C4#4, C5#3, D4#2, D4#6, D5#1, D5#3, D5#7, D6#1, E2#2, E2#3, E2#8, E4#1, F2#1, F5#3, H1#1, H1#7, H2#1, H2#2, H3#4, H4#1, H4#2, H5#1, S1#1, S2#5, T2#3, T2#4, U2#7, W1#5, W2#3, X1#1, Y1#5, Y2#1, Y2#7, Y3#2, Y3#9

16. **<Expo67NcfCa>** (group:Web) accessed 20141111
D2#4: Bill Dutfield http://expo67.ncf.ca/expo_africa_p2.html
D3#3: Michael Rougier, Life Magazine http://expo67.ncf.ca/expo67_pulp_and_paper_pavilion_construction_2.html
E3#2: Michael Rougier, Life Magazine http://expo67.ncf.ca/expo_67_construction_italy_pavilion.html
G5#2: Michael Rougier, Life Magazine http://expo67.ncf.ca/expo_67_construction_italy_pavilion.html
U1#1: Toronto: Thomas Nelson & Sons, 1968, Bruno Paul Stenson http://expo67.ncf.ca/expo_netherlands_p1.html
V1#2: Giles Clouatre http://expo67.ncf.ca/expo_67_austria_p1.html
Z1#8: National Archives of Canada http://expo67.ncf.ca/expo_german_p1.html
occurences: D2#4, D3#3, E3#2, G5#2, U1#1, V1#2, Z1#8

17. **<Exponiert>** (group:BookScan) Sigel, Paul. Exponiert. Berlin: Verlag Bauwesen, 2000.
occurences: Z1#4

18. **<Flickr_userAlanpPhoto>** (group:Flickr) alanp_photo
https://www.flickr.com/photos/38860277@N06/, accessed 2014
occurences: B1#4

19. **<Flickr_userAypexa>** (group:Flickr) Jael Herrera
https://www.flickr.com/photos/aypexa, accessed 2014
occurences: C1#3

20. **<Flickr_userBdutfield>** (group:Flickr) Bill Dutfield
https://www.flickr.com/photos/wdd100 accessed April 13, 2014
occurences: C3#7, D1#5, D2#6, D2#7, E3#5, G5#1, G5#3, V3#4, Z1#6

21. **<Flickr_userBellchan>** (group:Flickr) bellphoto.hk
https://www.flickr.com/photos/bellchan accessed May 18, 2014
occurences: H2#7

22. **<Flickr_userBolorocco>** (group:Flickr) Bolorocco
https://www.flickr.com/photos/bolorocco accessed May 18, 2014
occurences: A6#2, F5#9

23. **<Flickr_userCentralebibliotheek>** (group:Flickr) KU Leuven Bibliotheken - KU Leuven Libraries
https://www.flickr.com/photos/centralebibliotheek accessed 2014
occurences: B6#6, B6#7, B6#8

24. **<Flickr_userCesarCorona>** (group:Flickr) César Corona
https://www.flickr.com/photos/cesar_corona accessed April 13, 2014
occurences: F3#5, F6#8, H3#9, G2#2, T1#5, Y1#6

25. **<Flickr_userChazhutton>** (group:Flickr) Chaz
https://www.flickr.com/photos/chazhutton accessed April 13, 2014
occurences: D6#6, F2#4, Z2#8

26. **<Flickr_userChimaybleue>** (group:Flickr) chimaybleue
https://www.flickr.com/photos/54061828@N07 accessed Mai 29, 2014
occurences: D6#8, E2#5, E2#9, H5#7, W2#4

27. **<Flickr_userChris0405>** (group:Flickr) Chi Shao Chen
https://www.flickr.com/photos/chris0405 accessed May 18, 2014
occurences: A2#3, B4#1

28. **<Flickr_userDMorency>** (group:Flickr) David Morency
https://www.flickr.com/photos/107066872@N02 accessed May 18, 2014
2232247367_fc860653dd_o
occurences: E1#3

29. **<Flickr_userDannyOei>** (group:Flickr) Danny Oei
https://www.flickr.com/photos/dannyoei accessed June 13, 2014
occurences: T3#3

30. **<Flickr_userDisneykid>** (group:Flickr) disneyland.kid
https://www.flickr.com/photos/disneykid accessed April 13, 2014
occurences: C2#3, C7#5, S1#5, T2#5

31. **<Flickr_userErezUploadedByMagstb67>** (group:Flickr)
https://www.flickr.com user not recoverable, accessed 2014
occurences: A3#5, B2#6, E6#2, G1#6, X2#5, Z1#9
32. **<Flickr_userEspressobuzzUploadedByMagstb67>** (group:Flickr) EspressoBuzz
https://www.flickr.com/photos/espressobuzz accessed April 21, 2014
occurences: V1#7
33. **<Flickr_userExpomuseum>** (group:Flickr) ExpoMuseum
https://www.flickr.com/photos/expomuseum accessed April 13, 2014
occurences: A4#4, A6#3, B4#3, B5#4, C5#4, C5#7, D4#8, D6#9, E2#6, E4#8, E7#1, E7#3, E7#4, F2#5, F3#3, F6#4, H2#8, H3#6, H4#7, H7#7, H7#8, G2#1, G3#4, T3#2, T3#4, W2#1, X1#5, Y2#4, Y2#5, Y2#8
34. **<Flickr_userFrankschacht>** (group:Flickr) frank schacht
https://www.flickr.com/photos/frankschacht accessed May 18, 2014
occurences: A1#7, A2#4, A2#7, B4#2, C2#1, C2#2, C4#1, C6#2, C7#2, C7#3, D6#3, E2#7, H1#3, H3#3, H5#9, G4#1, U2#2, U2#3, U2#5, U2#6, Y1#4
35. **<Flickr_userGavinbloys>** (group:Flickr) gavin bloys
https://www.flickr.com/photos/gavinbloys accessed May 18, 2014
occurences: C7#1, E4#4
36. **<Flickr_userGenjiri>** (group:Flickr) er Frost
https://www.flickr.com/photos/8996686n02 accessed May 18, 2014
occurences: B5#2
37. **<Flickr_userHansziel>** (group:Flickr) hansziel99
https://www.flickr.com/photos/hansziel accessed 2014
occurences: H7#6
38. **<Flickr_userHtglss>** (group:Flickr) Jonghee Park
https://www.flickr.com/photos/htglss accessed June 13, 2014
occurences: G2#3
39. **<Flickr_userIweatherman>** (group:Flickr) iweatherman
https://www.flickr.com/photos/iweatherman accessed June 13, 2014
occurences: T1#2
40. **<Flickr_userJeffs4653>** (group:Flickr) Jeffs4653
https://www.flickr.com/photos/jeffs4653 accessed April 13, 2014
occurences: S3#4
41. **<Flickr_userJohnClaudi>** (group:Flickr) John Claudi
https://www.flickr.com user not recoverable, accessed 2014
11069025224_f6cc97a3d5_o
occurences: B6#1
42. **<Flickr_userKOota>** (group:Flickr) KOota
https://www.flickr.com user not recoverable, accessed 2014
occurences: D7#1, E5#4, F1#3, F7#5, U3#3, V2#5, X3#5
43. **<Flickr_userKhoavo>** (group:Flickr) khoavo
https://www.flickr.com/photos/khoavo accessed May 29, 2014
occurences: A7#4, S1#2
44. **<Flickr_userKimon>** (group:Flickr) Kimon Berlin
https://www.flickr.com/photos/kimon accessed May 18, 2014
occurences: A1#3, A2#2, B5#3, C1#2, C1#5, C2#5, C6#1, D4#7, E7#7, H1#2, H2#3, H4#8, G4#2, S1#4, T2#1, W1#1, Z2#6
45. **<Flickr_userKommandokraus>** (group:Flickr) Nils Jonsson
https://www.flickr.com/photos/kommandokraus accessed May 18, 2014
occurences: A2#6, S1#8
46. **<Flickr_userLaurentBaudoux>** (group:Flickr)
https://www.flickr.com user not recoverable, accessed 2014
304876264_d01ed04101_o
occurences: F7#2
47. **<Flickr_userLizstless>** (group:Flickr) Rick Webb
https://www.flickr.com/photos/lizstless accessed 2014
occurences: B3#5, V2#1
48. **<Flickr_userLzwwWw>** (group:Flickr) LzwwWw
https://www.flickr.com/photos/Lzww_Ww accessed 2014

occurences: Y2#9
49. **<Flickr_userMLouis>** (group:Flickr) m-louis, kingei
https://www.flickr.com/photos/m-louis/ accessed 2014
occurences: E5#1, G7#2
50. **<Flickr_userMagstb67>** (group:Flickr) Marc-A. G.
https://www.flickr.com/photos/61779764@N00 accessed 2014
8218671921_930da04a04_o
occurences: A3#3, B2#2, D1#1, D1#3, D1#4, G1#8, G5#5, V1#8, X2#4, Z1#2, Z1#3

51. **<Flickr_userMarcaurel>** (group:Flickr) Marc Aurel
https://www.flickr.com/photos/marcaurel accessed May 18, 2014
occurences: A2#1
52. **<Flickr_userMeiguoxing>** (group:Flickr) meiguo Xing
https://www.flickr.com/photos/23665309@N02 accessed May 29, 2014
occurences: E4#2, G4#5
53. **<Flickr_userMikeBulter>** (group:Flickr) mike.bulter
https://www.flickr.com/photos/36459507@N07 accessed 2014
occurences: F4#7
54. **<Flickr_userMrTl>** (group:Flickr) Mr Tl
https://www.flickr.com user not recoverable, accessed 2014
occurences: S1#7
55. **<Flickr_userNyclondonguy>** (group:Flickr) nyclondonguy
https://www.flickr.com/photos/25156558@N05 accessed 2014
occurences: B1#2, D7#4, F7#3, U3#2, U3#4, V2#3, V2#8
56. **<Flickr_userPetespix75>** (group:Flickr) Henry Petermann
https://www.flickr.com/people/46633980@N04 accessed April 14, 2014
occurences: G1#7, U3#1, V1#9
57. **<Flickr_userPicturenarrative>** (group:Flickr) picturenarrative
https://www.flickr.com/photos/picturenarrative accessed May 18, 2014
occurences: D6#4, F5#6
58. **<Flickr_userPittigliani2005>** (group:Flickr) pittigliani2005
https://www.flickr.com/photos/37925259@N00 accessed May 18, 2014
occurences: H7#2
59. **<Flickr_userSSchleicher>** (group:Flickr) Simon Schleicher
https://www.flickr.com/photos/80005875@N04 accessed June 13, 2014
occurences: F6#6, F6#7
60. **<Flickr_userSnapshotunlimited>** (group:Flickr) SnapShotUnlimited
https://www.flickr.com/photos/snapshotunlimited accessed May 18, 2014
occurences: C6#3, Y1#3
61. **<Flickr_userSophieetfred>** (group:Flickr) Sophie et Fred
https://www.flickr.com/photos/47412998@N08 accessed May 18, 2014
occurences: A4#3
62. **<Flickr_userSteelersliu>** (group:Flickr) Felix Liu
https://www.flickr.com/photos/liuyuhong accessed May 18, 2014
occurences: A2#5, E2#1, E7#6, H5#3, H5#5, S2#1
63. **<Flickr_userStephanegroleau>** (group:Flickr) Stéphane Groleau
https://www.flickr.com/photos/stephanegroleau accessed May 18, 2014
occurences: A1#6, A1#8, A1#9
64. **<Flickr_userThePieShopsCollection>** (group:Flickr) Cardboard America Collection
https://www.flickr.com/photos/hollywoodplace accessed April 13, 2014
occurences: D3#1, E3#1, G1#1, G1#4
65. **<Flickr_userTravelingchris1972>** (group:Flickr) Chris Hollis
https://www.flickr.com/photos/roosterhollis accessed June 13, 2014
occurences: T1#6
66. **<Flickr_userWentaoYin12>** (group:Flickr) Beijing1211
https://www.flickr.com/photos/7720941@N08 accessed May 18, 2014
occurences: A6#1, A7#3, A7#5, C4#2, C5#5, C5#8, C5#9, D5#5, E4#6, T2#2, T2#7
67. **<Flickr_userWojtekgurak>** (group:Flickr) Wojtek Gurak
https://www.flickr.com/photos/wojtekgurak accessed May 18, 2014
occurences: A1#5, A4#5, A4#7, A5#2, A5#6, C1#1, C5#1, C5#2, D6#5, E4#5, H1#5, H1#6, H3#1, H3#2, H3#7, S2#4, W2#2, Y1#1, Y1#2, Y3#8, Z2#1, Z2#9
68. **<GbphotodidacticalCa>** (group:Web) Ghislain Bonneau
http://gbphotodidactical.ca/page-photo-Expo-67.html (site will Close down the 21 March 2022) accessed 2014
occurences: B2#9, D1#9, E1#5, V3#5, V3#8
69. **<GoogleEarth>** (group:GoogleEarth)
https://earth.google.com/web/ "Aerial Images From Hannover World Exposition Site" 2006, Google Earth, accessed 2014
the original screenshots are cropped for the research purpose
occurences: F4#5, H7#4, G3#3
70. **<GoogleMaps>** (group:GoogleMaps)
https://www.google.at/maps "Satellite Images From Shanghai World Exposition Site", 2010, Google Maps, accessed 2014
the original screenshots are cropped for the research purpose
occurences: B4#5, B5#7, D5#2, F2#2, F6#5, H3#5, H4#5, S1#3, S2#2, W1#2, Y3#3, Z2#5

71. **<HelenhardNo>** (group:Web) Helen & Hard
https://helenhard.no accessed 2014
occurences: Z2#7

72. **<KawaguchiEngineers>** (group:Exhibition) Kawaguchi Engineers
Photos taken from posters on the exhibition "the Anniversary Symposium of the IASS," Valencia, 2009.
https://kawa-struc.com/en/
occurences: F1#5, F1#7

73. **<KnippershelbigCom>** (group:Web) knippershelbig
https://knippershelbig.com/de/projekte/norwegischer-pavillon accessed 2014
occurences: Z2#4

74. **<Lemog3dBblogspot>** (group:Web) Laurent ANTOINE "LeMog"
http://lemog3d.blogspot.com/2010/08/expo-58-projet-bie-film-n4-texturing.html accessed
occurences: B6#9

75. **<Life_byCarlMydans>** (group:Archive) Carl Mydans
"Expo '70" photographer Carl Mydans 1970, LIFE (c) Time Inc.
https://www.life.com/photographer/carl-mydans/ accessed 2014
occurences: E5#5, X3#1, X3#3, Z3#1

76. **<Magnum_byFerdinandoScianna>** (group:Web) Magnum Photos - Ferdinando Scianna
https://www.magnumphotos.com/photographer/ferdinando-scianna/
Photographs found 2014
occurences: B1#7, B1#8, B1#9, E5#2

77. **<Magnum_byReneBruni>** (group:Web) Magnum Photos - Rene Burri
https://www.magnumphotos.com/photographer/rene-burri/
Photographs found 2014
occurences: V2#7

78. **<NiftyComSaekiSin>** (group:Web) nifty.com - Saeki Sin
https://www.nifty.com user not recoverable, accessed 2014
occurences: D7#3, G7#4, V2#4, X3#4

79. **<OdasanS48XreaCom>** (group:Web) Odasan
http://odasan.s48.xrea.com/expo70/expo2.html accessed 2014
http://odasan.s48.xrea.com/expo70/
occurences: B3#3, D7#5, V2#2

80. **<PJ>** (group:Direct)
Special value: By the Author Philipp Jurewicz
occurences: A1#4, A4#6, A4#8, A4#9, A6#5, B5#5, B5#6, C6#5, D4#1, D4#5, D4#9, E4#7, E7#2, F5#1, F5#2, F5#4, F5#7, H2#4, H2#5, H2#6, H4#4, H5#6, H6#1, H6#3, H6#4, G6#1, G6#6, G6#7, G6#8, G6#9, W1#3, W3#1, W3#4, W3#5, Y1#9, Y2#6, Y3#7

81. **<Panoramio_user(utf8)_(3705168)>** (group:Panoramio)
https://www.panoramio.com/ Google Inc. site discontinued 2016, accessed 2014
occurences: F6#2, F6#3, F6#9, T1#1, T3#1

82. **<Panoramio_user1400530_(utf81961)>** (group:Panoramio)
https://www.panoramio.com/ Google Inc. site discontinued 2016, accessed 2014
occurences: D4#3, D5#4, D5#6

83. **<Panoramio_user1400530_(utf8_1961)>** (group:Panoramio)
https://www.panoramio.com/ Google Inc. site discontinued 2016, accessed 2014
occurences: C4#3, H3#8, H4#9

84. **<Panoramio_user1476663_(cnUtf8)>** (group:Panoramio)
https://www.panoramio.com/ Google Inc. site discontinued 2016, accessed 2014
occurences: G4#3

85. **<Panoramio_user1558204Rucativaca>** (group:Panoramio)
https://www.panoramio.com/ Google Inc. site discontinued 2016, accessed 2014
occurences: G6#5

86. **<Panoramio_user239280_(Baycrest)>** (group:Panoramio)
https://www.panoramio.com/ Google Inc. site discontinued 2016, accessed 2014
occurences: U2#1

87. **<Panoramio_user2481456_(JunjunGuo)>** (group:Panoramio)
https://www.panoramio.com/ Google Inc. site discontinued 2016, accessed 2014
occurences: Y2#2

88. **<Panoramio_user2485865_(ThomasPrinz)>** (group:Panoramio)
https://www.panoramio.com/ Google Inc. site discontinued 2016, accessed 2014
occurences: F5#5

89. **<Panoramio_user3962419_(DuyiHan)>** (group:Panoramio)
https://www.panoramio.com/ Google Inc. site discontinued 2016, accessed 2014
occurences: D6#2, W1#4

90. **<Panoramio_user557748(jsduo44)>** (group:Panoramio)
https://www.panoramio.com/ Google Inc. site discontinued 2016, accessed 2014
occurences: F2#3, H4#6

91. **<Panoramio_user604433_(utf8)>** (group:Panoramio)
https://www.panoramio.com/ Google Inc. site discontinued 2016, accessed 2014
occurences: A5#3, X1#3, X1#4

92. **<Panoramio_user604433_(吉易)>** (group:Panoramio)
https://www.panoramio.com/ Google Inc. site discontinued 2016, accessed 2014
occurences: H5#8, Z2#2

93. **<Panoramio_user6501470_(utf8)>** (group:Panoramio)
https://www.panoramio.com/ Google Inc. site discontinued 2016, accessed 2014
occurences: H4#3

94. **<Panoramio_user710947_(Dxinwei)>** (group:Panoramio)
https://www.panoramio.com/ Google Inc. site discontinued 2016, accessed 2014
occurences: Z2#3

95. **<Panoramio_user775448-brickl>** (group:Panoramio)
https://www.panoramio.com/ Google Inc. site discontinued 2016, accessed 2014
occurences: F4#1, F4#2, F4#3, F4#4, H7#1, H7#3, G3#5, G3#6, G3#7, G3#8, G3#9

96. **<Panoramio_user84422NunoMiguelPaisTrabulo>** (group:Panoramio)
https://www.panoramio.com/ Google Inc. site discontinued 2016, accessed 2014
occurences: G6#4

97. **<Panoramio_userPlumgarden_(54048)>** (group:Panoramio)
https://www.panoramio.com/ Google Inc. site discontinued 2016, accessed 2014
occurences: F6#1, G2#4, G2#5, T1#3, T1#4, T3#5

98. **<Panoramio_userXiemingjun3616879>** (group:Panoramio)
https://www.panoramio.com/ Google Inc. site discontinued 2016, accessed 2014
occurences: Y3#1

99. **<Photobucket_userLemog>** (group:Web) Laurent ANTOINE "LeMog"
https://photobucket.com accessed 2014
occurences: B6#3, B6#4

100. **<PinkTentakleCom>** (group:Web) Dimiter Dimitrov
http://pinktentacle.com/2010/03/photos-expo-70/ accessed March 21, 2014
occurences: D7#6

101. **<PinterestArchitekturaPh>** (group:Web)
https://www.pinterest.com accessed 2014
occurences: B3#1

102. **<PoltrackNet_byJohnPoltrack>** (group:Web) John M Poltrack
https://poltrack.net/ accessed 2014
Photographs also available at user Flickr account:
B1#1 https://www.flickr.com/photos/poltracknet/32331905378/in/album-72157702448582074/
F1#1 https://www.flickr.com/photos/poltracknet/46153314452/in/album-72157702448582074/
occurences: B1#1, F1#1

103. **<RobertLavigneCom>** (group:Web) Robert Lavigne
http://www.robert-lavigne.com accessed 2014
occurences: C3#8, E1#2

104. **<Skyscrapercity_byflymordecai>** (group:Web)
https://www.skyscrapercity.com/threads/convention-centers-and-exhibition-halls.472263/page-13#post-24711536
accessed 2014
Original Book Source: Locsin Leandro V Nicholas Polites Akio Kawasumi Norio Ishiguro and Zóbel de Ayala Fernando. 1977. The Architecture of Leandro V. Locsin [1St ed.] ed. New York: Weatherhill.
occurences: B3#4

105. **<Sonynaviblogsonetnejp>** (group:Web)
https://1970-photo-world.blog.ss-blog.jp/2010-05-20 accessed 2014
occurences: F1#6, F7#4, X3#2, Z3#5

106. **<StatesOfArchitectures_byNicLehoux>** (group:BookScan)
Riera Ojeda, Oscar, Rodolphe El-Khoury, and Andrew Payne. States of Architecture in the Twenty-First Century: New Directions from the Shanghai World Expo, 2011.
occurences: B5#8, B5#9, E7#5, E7#9, H5#4, S1#6, S2#3

107. **<TokyoskyTo>** (group:Web)
http://tokyosky.sub.jp/tokyosky_webmasters_blog/assets_c/2012/01/EXPO70-142.html accessed 2014
occurences: B1#5

108. **<UNSW_LSRU_Archive>** (group:Archive) Sydney, University of New South Wales (UNSW), Lightweight Structures Research Unit (LSRU)
occurences: F1#2, F1#4, Z3#2, Z3#4

109. **<Weltausstellungen>** (group:BookScan) Garn Andrew and Cornelius Brand. 2008. Weltausstellungen 1933 - 2005 Architektur Design Graphik 1. Aufl ed. München: Dt. Verl.-Anst.
occurences: B7#3, B7#5, F7#6

110. **<Wikipedia_byAxelHH>** (group:Wikipedia) Axel Hindemith
"Deutscher Pavillon der Expo 2000", Axel Hindemith, Mai 2011,
CC BY-SA 3.0
https://de.wikipedia.org/wiki/Datei:Expo_2000_Deutscher_Pavillon_2011.jpg accessed 2014
occurences: G3#1

111. **<Wikipedia_byBallonSzDe>** (group:Wikipedia) Ballon-sz.de
"Gelände der Expo 2000 in Hannover im Jahr 2007"
CC BY-SA 2.0 DE
https://de.wikipedia.org/wiki/Datei:Expogel%C3%A4nde_Heute_(2007).jpg accessed 2014
occurences: H7#9

112. **<Wikipedia_byJensBludau>** (group:Wikipedia) Jens Bludau
"Japanischer Pavillon von Shigeru Ban", Jens Bludau (own work), Oktober 2000,
CC BY-SA 3.0
https://commons.wikimedia.org/wiki/File:Expo2000Japan.jpg accessed 2014
occurences: F3#1

113. **<Wikipedia_byMisburg3014>** (group:Wikipedia) Misburg3014 (own work)
"Pavilion of Hope ("Expo Whale") in Expo-Park (Hannover, Germany), emblem of Expo 2000", uploaded 22. November 2009
CC BY-SA 3.0
https://de.wikipedia.org/wiki/Datei:Hannover_Expo-Wal-2009.jpg accessed 2014
occurences: F4#6

114. **<Wikipedia_byWouterhagens>** (group:Wikipedia) "Expo 1958 Philips Pavilion", created July 1958, uploaded 20 August 2008 Wouter Hagens (own work)

CC BY-SA 3.0
https://en.wikipedia.org/wiki/Philips_Pavilion#/media/File:Expo58_building_Philips.jpg accessed 2014
"Expo58 Belgie kaart A", created July 1958, uploaded 20 August 2008
https://commons.wikimedia.org/wiki/File:Expo58_Belgie_kaart_A.jpg accessed 2014
occurences: B6#5, B7#4

115. **<WirtschaftswundermuseumDe>** (group:Web)
https://www.wirtschaftswundermuseum.de/expo-1958-1.html accessed 2014
occurences: B6#2

116. **<WorldsfaircommunityOrg_byBillCotter>** (group:Web) Bill Cotter
http://www.worldsfaircommunity.org accessed 2014
occurences: Z3#3

117. **<WsjCom>** (group:Web) The Wall Street Journal
https://s.wsj.net/public/resources/images/OB-HQ504_0223ex_H_20100223040326.jpg accessed 2014
occurences: F2#7

118. **<YouTube_userRichOglesby>** (group:YouTube) youtube - Rich Oglesby

https://www.youtube.com/channel/UC0WAqiR4urAyG-RMPaz0FNA
https://www.youtube.com/watch?v=6NnxVGWzR_Y accessed 2014
occurences: G7#3

119. **<YouTube_userTyokutoku>** (group:YouTube) youtube - Tyokutoku
https://www.youtube.com user not recoverable, accessed 2014
occurences: B3#2, U3#5

This page intentionally left blank in print layout

This page intentionally left blank in print layout

Appendix B

Weak References (Named Relationships)

part of doctoral thesis

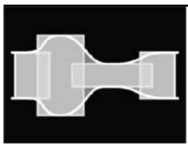
Building Shape Classification

Philipp Jurewicz 2023

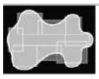
Note about image references:

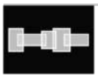
This appendix is part of the doctoral thesis “Building Shape Classification” at TU Wien.
All icons in this appendix have been created by the author.

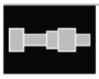
Classification Set: **Spacing** (Page 1/2)

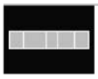


spacingBlob

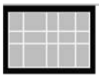

50%
Normal
spacingPlanarBlob

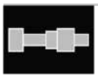

50%
Normal
spacingOverlapPartial

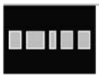

25%
Weak
spacingContactPartial

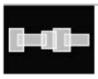

25%
Weak
spacingContactMatching

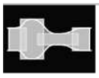
spacingContactMatching


50%
Normal
spacingPlanarContactMatching


50%
Normal
spacingContactPartial

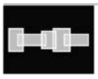

25%
Weak
spacingGapMatching

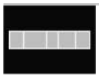

25%
Weak
spacingOverlapPartial


25%
Weak
spacingBlob

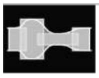
spacingContactPartial


50%
Normal
spacingPlanarContactPartial

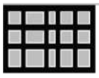

50%
Normal
spacingOverlapPartial


50%
Normal
spacingContactMatching


25%
Weak
spacingGapPartial


25%
Weak
spacingBlob

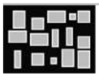
spacingGapMatching


50%
Normal
spacingPlanarGapMatching

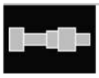

50%
Normal
spacingGapPartial

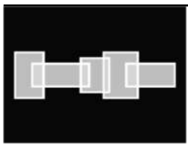

25%
Weak
spacingContactMatching

spacingGapPartial

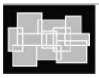

50%
Normal
spacingPlanarGapPartial

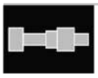

50%
Normal
spacingGapMatching

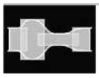

25%
Weak
spacingContactPartial

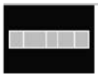


spacingOverlapPartial

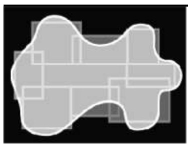

50%
Normal
spacingPlanarOverlapPartial


50%
Normal
spacingContactPartial

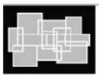

50%
Normal
spacingBlob

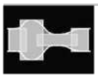

25%
Weak
spacingContactMatching

Classification Set: **Spacing** (Page 2/2)

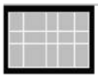


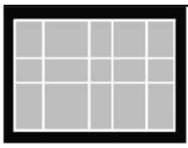
spacingPlanarBlob


50% Normal
spacingPlanarOverlapPartial


50% Normal
spacingBlob

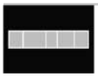

25% Weak
spacingPlanarContactPartial

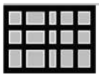

25% Weak
spacingPlanarContactMatching

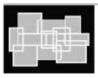


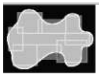
spacingPlanarContactMatching

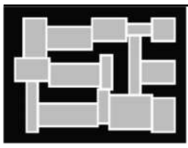

50% Normal
spacingPlanarContactPartial


50% Normal
spacingContactMatching

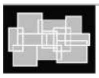

25% Weak
spacingPlanarGapMatching

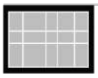

25% Weak
spacingPlanarOverlapPartial

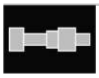

25% Weak
spacingPlanarBlob

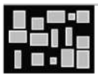


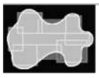
spacingPlanarContactPartial

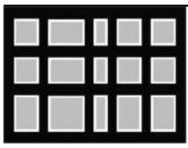

50% Normal
spacingPlanarOverlapPartial


50% Normal
spacingPlanarContactMatching

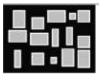

50% Normal
spacingContactPartial

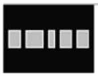

25% Weak
spacingPlanarGapPartial

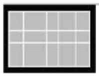

25% Weak
spacingPlanarBlob



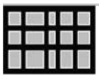
spacingPlanarGapMatching


50% Normal
spacingPlanarGapPartial


50% Normal
spacingGapMatching

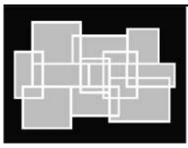

25% Weak
spacingPlanarContactMatching

spacingPlanarGapPartial

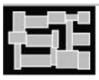

50% Normal
spacingPlanarGapMatching

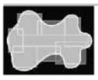

50% Normal
spacingGapPartial

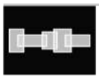

25% Weak
spacingPlanarContactPartial

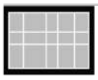


spacingPlanarOverlapPartial


50% Normal
spacingPlanarContactPartial

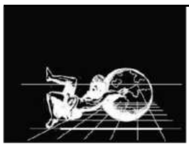

50% Normal
spacingPlanarBlob


50% Normal
spacingOverlapPartial

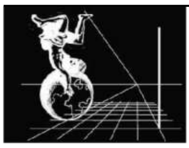

25% Weak
spacingPlanarContactMatching

Classification Set: **Orientation**

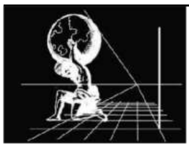
orientationDiagonal



orientationHorizontal



orientationVerticalDown



orientationVerticalUp

Classification Set: **Cardinality**

0 cardinality

card0

---

1 cardinality

card1

---

2 cardinality

card2

3 cardinality	25% Weak	card3

---

3 cardinality

card3

~5 cardinality	50% Normal	cardApproximatly5
2 cardinality	25% Weak	card2

~13 or more

cardApproximatly13OrMore

~8 cardinality	75% Strong	cardApproximatly8
~5 cardinality	25% Weak	cardApproximatly5

~5 cardinality

cardApproximatly5

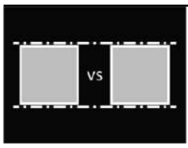
~8 cardinality	50% Normal	cardApproximatly8
3 cardinality	50% Normal	card3
~13 or more	25% Weak	cardApproximatly13OrMore

~8 cardinality

cardApproximatly8

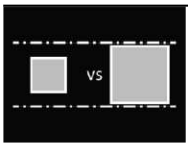
~13 or more	75% Strong	cardApproximatly13OrMore
~5 cardinality	50% Normal	cardApproximatly5

Classification Set: **RelativeSize**



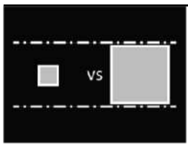
sizeApproximatelySame

- 75% Strong — sizeSmallerSlightly
- 75% Strong — sizeLargerSlightly
- 50% Normal — sizeSmaller
- 50% Normal — sizeLarger
- 25% Weak — sizeSmallerSignificant
- 25% Weak — sizeLargerSignificant



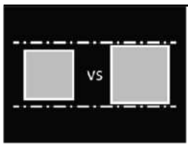
sizeLarger

- 75% Strong — sizeLargerSlightly
- 75% Strong — sizeLargerSignificant
- 50% Normal — sizeApproximatelySame
- 25% Weak — sizeSmallerSlightly



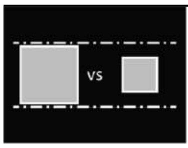
sizeLargerSignificant

- 75% Strong — sizeLarger
- 50% Normal — sizeLargerSlightly
- 25% Weak — sizeApproximatelySame
- 10% Very Weak — sizeSmallerSlightly



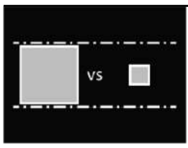
sizeLargerSlightly

- 75% Strong — sizeApproximatelySame
- 75% Strong — sizeLarger
- 50% Normal — sizeSmallerSlightly
- 50% Normal — sizeLargerSignificant
- 25% Weak — sizeSmaller
- 10% Very Weak — sizeSmallerSignificant



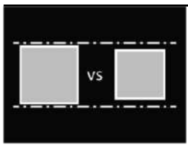
sizeSmaller

- 75% Strong — sizeSmallerSignificant
- 75% Strong — sizeSmallerSlightly
- 50% Normal — sizeApproximatelySame
- 25% Weak — sizeLargerSlightly



sizeSmallerSignificant

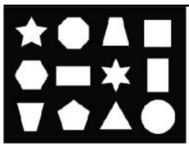
- 75% Strong — sizeSmaller
- 50% Normal — sizeSmallerSlightly
- 25% Weak — sizeApproximatelySame
- 10% Very Weak — sizeLargerSlightly



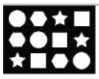
sizeSmallerSlightly

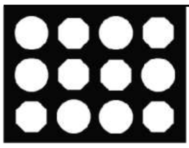
- 75% Strong — sizeSmaller
- 75% Strong — sizeApproximatelySame
- 50% Normal — sizeSmallerSignificant
- 50% Normal — sizeLargerSlightly
- 25% Weak — sizeLarger
- 10% Very Weak — sizeLargerSignificant

Classification Set: **Variety**

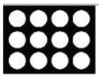


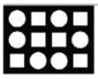
varietyFull

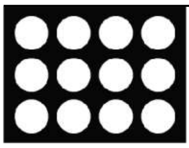

50%
Normal
varietySignificant



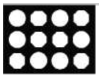
varietyMinor

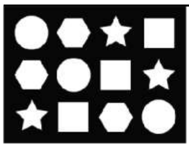

50%
Normal
varietyNone


50%
Normal
varietySome

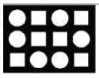


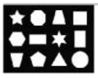
varietyNone

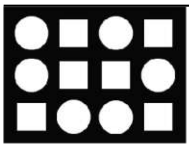

50%
Normal
varietyMinor



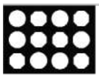
varietySignificant

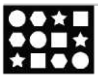

50%
Normal
varietySome


50%
Normal
varietyFull



varietySome


50%
Normal
varietyMinor


50%
Normal
varietySignificant

Classification Set: **Randomness**

randomMinor


50%
Normal
randomSome


50%
Normal
randomNone

randomNone


50%
Normal
randomMinor

randomSignificant

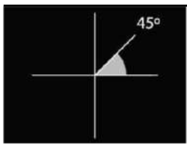

50%
Normal
randomSome

randomSome


50%
Normal
randomSignificant

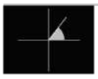

50%
Normal
randomMinor

Classification Set: **Angle** (Page 1/2)



angleApproximately45

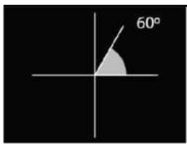
75% Strong
angleApproximately60


75% Strong
angleAstute

50% Normal
anglePerpendicularOff

25% Weak
anglePerpendicularOffSignificantly

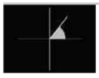
25% Weak
anglePerpendicularOffMinor



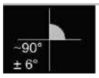
angleApproximately60

75% Strong
angleApproximately45

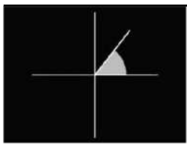
50% Normal
anglePerpendicularOff


50% Normal
angleAstute

25% Weak
anglePerpendicularOffSignificantly

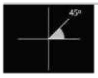


25% Weak
anglePerpendicularOffMinor



angleAstute

75% Strong
anglePerpendicularOff



75% Strong
angleApproximately45

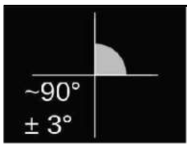
50% Normal
anglePerpendicularOffSignificantly

50% Normal
angleApproximately60

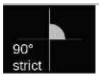
angleObtuse

50% Normal
anglePerpendicularOffSignificantly

50% Normal
anglePerpendicularOff



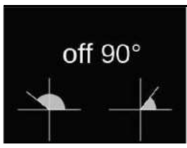
anglePerpendicularApproximatly



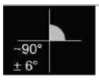
90% Very Strong
anglePerpendicularStrict

50% Normal
anglePerpendicularOffMinor

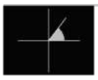
25% Weak
anglePerpendicularOff



anglePerpendicularOff



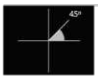
75% Strong
anglePerpendicularOffMinor


75% Strong
angleAstute

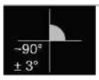
50% Normal
anglePerpendicularOffSignificantly


50% Normal
angleObtuse

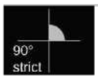
50% Normal
angleApproximately60



50% Normal
angleApproximately45

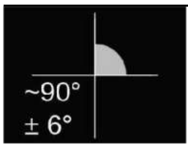


25% Weak
anglePerpendicularApproximatly



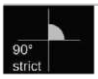
10% Very Weak
anglePerpendicularStrict

Classification Set: **Angle** (Page 2/2)



anglePerpendicularOffMinor

75%
Strong
anglePerpendicularOff

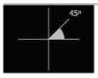


50%
Normal
anglePerpendicularStrict

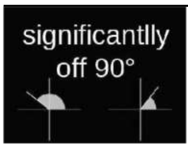
50%
Normal
anglePerpendicularApproximatly

25%
Weak
anglePerpendicularOffSignificantly

25%
Weak
angleApproximately60

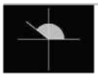


25%
Weak
angleApproximately45



anglePerpendicularOffSignificantly

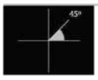
50%
Normal
anglePerpendicularOff


50%
Normal
angleObtuse

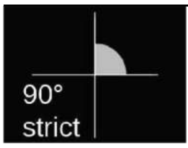

50%
Normal
angleAstute

25%
Weak
anglePerpendicularOffMinor

25%
Weak
angleApproximately60



25%
Weak
angleApproximately45



anglePerpendicularStrict

90%
Very Strong
anglePerpendicularApproximatly

50%
Normal
anglePerpendicularOffMinor

10%
Very Weak
anglePerpendicularOff

Classification Set: **Edge**

edgeChamfer


50% Normal
edgeSharp


25% Weak
edgeSmooth


25% Weak
edgeFillet

edgeFillet


50% Normal
edgeFillet


25% Weak
edgeSmooth

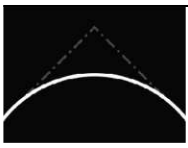

25% Weak
edgeChamfer


25% Weak
edgeSharp

edgeSharp


50% Normal
edgeChamfer


25% Weak
edgeFillet

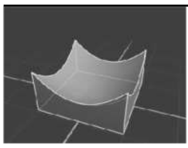


edgeSmooth

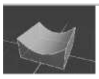

25% Weak
edgeChamfer

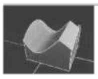

25% Weak
edgeFillet

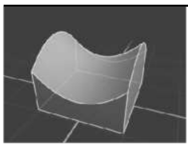
Classification Set: **Curvature** (Page 1/2)



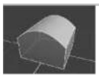
curvatureConcaveConcave

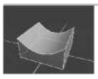

50% Normal
curvatureConcaveStraight

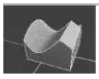

25% Weak
curvatureMixedMixed

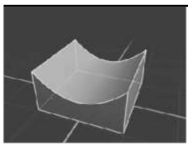


curvatureConcaveConvex

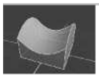

50% Normal
curvatureConvexStraight

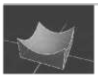

50% Normal
curvatureConcaveStraight

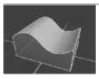

25% Weak
curvatureMixedMixed

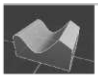


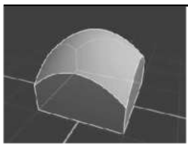
curvatureConcaveStraight


50% Normal
curvatureConcaveConvex

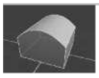

50% Normal
curvatureConcaveConcave

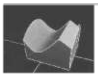

50% Normal
curvatureUndulation

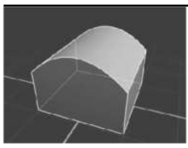

25% Weak
curvatureMixedStraight



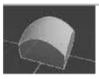
curvatureConvexConvex

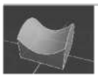

50% Normal
curvatureConvexStraight

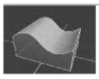

25% Weak
curvatureMixedMixed

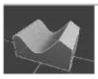


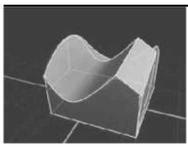
curvatureConvexStraight


50% Normal
curvatureConvexConvex

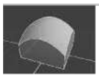

50% Normal
curvatureConcaveConvex

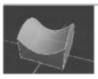

50% Normal
curvatureUndulation

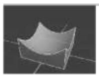

25% Weak
curvatureMixedStraight

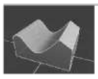


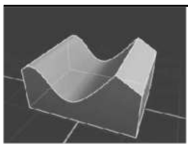
curvatureMixedMixed


25% Weak
curvatureConvexConvex

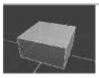

25% Weak
curvatureConcaveConvex

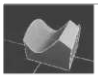

25% Weak
curvatureConcaveConcave

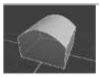

25% Weak
curvatureMixedStraight

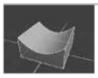


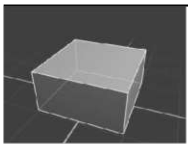
curvatureMixedStraight


25% Weak
curvaturePlanar

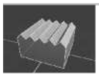

25% Weak
curvatureMixedMixed

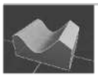

25% Weak
curvatureConvexStraight


25% Weak
curvatureConcaveStraight

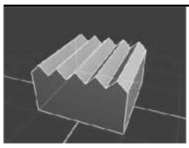


curvaturePlanar

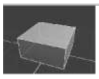

50% Normal
curvaturePlanarZigZag


25% Weak
curvatureMixedStraight

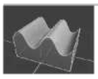
Classification Set: **Curvature** (Page 2/2)



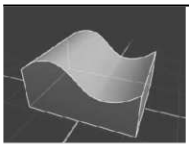
curvaturePlanarZigZag



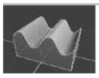
50%
Normal
curvaturePlanar



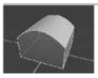
25%
Weak
curvatureUndulationWaves



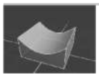
curvatureUndulation



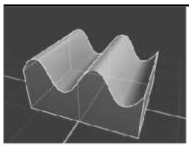
50%
Normal
curvatureUndulationWaves



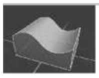
50%
Normal
curvatureConvexStraight



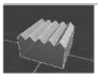
50%
Normal
curvatureConcaveStraight



curvatureUndulationWaves



50%
Normal
curvatureUndulation

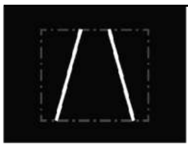


25%
Weak
curvaturePlanarZigZag

Classification Set: **Tilt** (Page 1/2)

tiltApproximatelyNone

- 50% Normal — tiltWidenMinor
- 50% Normal — tiltWiden
- 50% Normal — tiltTaperMinor
- 25% Weak — tiltTaper

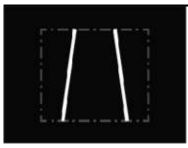


tiltTaper

- 75% Strong — tiltTaperMinor
- 75% Strong — tiltTaperSignificant
- 75% Strong — tiltTaperComplete
- 25% Weak — tiltApproximatelyNone

tiltTaperComplete

- 90% Very Strong — tiltTaperSignificant
- 75% Strong — tiltTaper
- 50% Normal — tiltTaperMinor

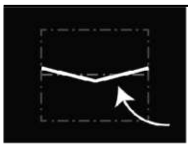


tiltTaperMinor

- 75% Strong — tiltTaper
- 50% Normal — tiltApproximatelyNone
- 50% Normal — tiltTaperSignificant
- 50% Normal — tiltTaperComplete
- 25% Weak — tiltWidenMinor

tiltTaperSignificant

- 90% Very Strong — tiltTaperComplete
- 75% Strong — tiltTaper
- 50% Normal — tiltTaperMinor

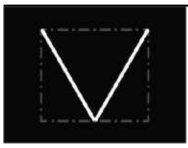


tiltViewFromBelow

- 90% Very Strong — tiltWidenComplete
- 75% Strong — tiltWidenSignificant
- 50% Normal — tiltWiden
- 25% Weak — tiltWidenMinor

tiltWiden

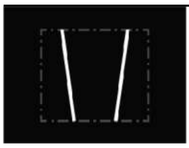
- 75% Strong — tiltWidenMinor
- 75% Strong — tiltWidenSignificant
- 75% Strong — tiltWidenComplete
- 50% Normal — tiltApproximatelyNone
- 50% Normal — tiltViewFromBelow



tiltWidenComplete

- 90% Very Strong — tiltWidenSignificant
- 90% Very Strong — tiltViewFromBelow
- 75% Strong — tiltWiden
- 50% Normal — tiltWidenMinor

Classification Set: **Tilt** (Page 2/2)



tiltWidenMinor

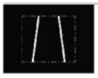

75%
Strong
tiltWiden


50%
Normal
tiltApproximatelyNone


50%
Normal
tiltWidenSignificant


50%
Normal
tiltWidenComplete

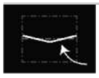

25%
Weak
tiltViewFromBelow


25%
Weak
tiltTaperMinor

tiltWidenSignificant

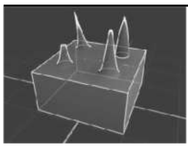

90%
Very Strong
tiltWidenComplete


75%
Strong
tiltWiden

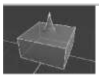

75%
Strong
tiltViewFromBelow

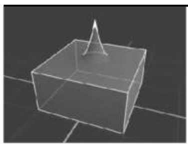

50%
Normal
tiltWidenMinor

Classification Set: **Feature** (Page 1/2)

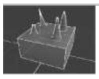


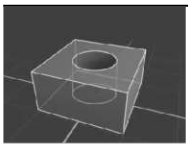
featureHighpointMultiple


75%
Strong
featureHighpointSingle

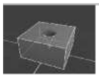


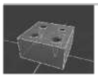
featureHighpointSingle

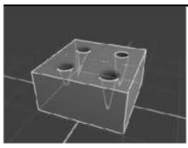

75%
Strong
featureHighpointMultiple



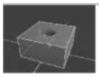
featureLowpointCourt

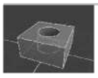

50%
Normal
featureLowpointSingle

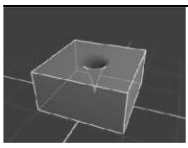

25%
Weak
featureLowpointMultiple



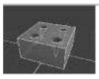
featureLowpointMultiple

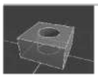

75%
Strong
featureLowpointSingle

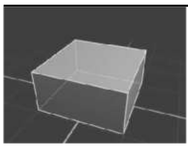

25%
Weak
featureLowpointCourt



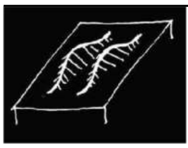
featureLowpointSingle


75%
Strong
featureLowpointMultiple


50%
Normal
featureLowpointCourt

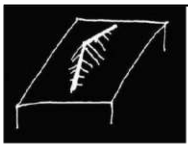


featureNoSignificant



featureRidgeMultiple


75%
Strong
featureRidgeSingle

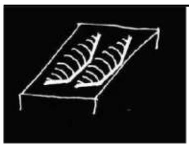


featureRidgeSingle


75%
Strong
featureRidgeMultiple

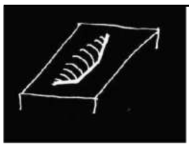
featureSpiral

Classification Set: **Feature** (Page 2/2)



featureValleyMultiple

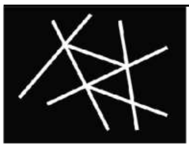
75%
Strong
featureValleySingle



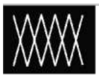
featureValleySingle

75%
Strong
featureValleyMultiple

Classification Set: **Texture**



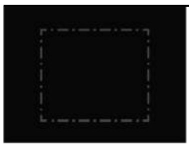
textureFacetedIrregular



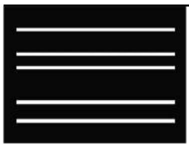
50%
Normal
textureFacetedRegular

textureFacetedRegular

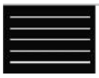
50%
Normal
textureFacetedIrregular



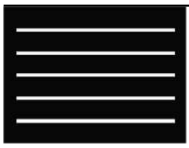
textureSmooth



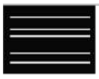
textureStripedIrregular



50%
Normal
textureStripedRegular



textureStripedRegular



50%
Normal
textureStripedIrregular

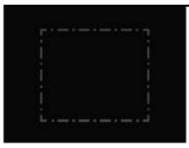
Classification Set: **Lattice**

BEND

latticeBend

TWIST 25% Weak

latticeTwist



latticeNoSignificant

latticeNoise

SHEAR

latticeShear

U STRECH

latticeStrechUnproportional

TWIST

latticeTwist

BEND 25% Weak

latticeBend

Classification Set: **Proportion** (Page 1/6)

proportionM1ZeroM1

90% Very Strong proportionP1ZeroZero	75% Strong proportionM1ZeroM2	75% Strong proportionZeroZeroZero	75% Strong proportionP1ZeroP1
75% Strong proportionP2ZeroZero	75% Strong proportionZeroZeroM1	75% Strong proportionP1ZeroM1	75% Strong proportionM1ZeroZero
75% Strong proportionM2ZeroM1	75% Strong proportionP2ZeroP1	50% Normal proportionZeroZeroP1	50% Normal proportionZeroZeroM2
50% Normal proportionP2ZeroM1	50% Normal proportionM2ZeroZero	50% Normal proportionP2ZeroP2	50% Normal proportionM2ZeroM2

proportionM1ZeroM2

90% Very Strong proportionP1ZeroM1	75% Strong proportionP2ZeroM1	75% Strong proportionZeroZeroM2	75% Strong proportionP1ZeroZero
75% Strong proportionZeroZeroM1	75% Strong proportionP1ZeroM2	75% Strong proportionP2ZeroZero	75% Strong proportionM1ZeroM1
75% Strong proportionM2ZeroM2	50% Normal proportionP2ZeroM2	50% Normal proportionZeroZeroZero	50% Normal proportionM2ZeroM1
50% Normal proportionP2ZeroP1			

proportionM1ZeroP1

90% Very Strong proportionP1ZeroP2	75% Strong proportionP1ZeroP1	75% Strong proportionZeroZeroP1	75% Strong proportionM1ZeroZero
75% Strong proportionZeroZeroP2	75% Strong proportionP2ZeroP2	75% Strong proportionM1ZeroP2	75% Strong proportionM2ZeroP1
50% Normal proportionP2ZeroP1	50% Normal proportionZeroZeroZero	50% Normal proportionM2ZeroP2	50% Normal proportionM2ZeroZero

proportionM1ZeroP2

75% Strong proportionZeroZeroP2	75% Strong proportionM1ZeroP1	75% Strong proportionP1ZeroP2	75% Strong proportionM2ZeroP2
50% Normal proportionZeroZeroP1	50% Normal proportionM2ZeroP1		

Classification Set: **Proportion** (Page 2/6)

proportionM1ZeroZero

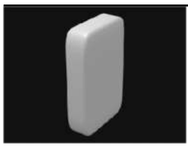
90%	Very Strong	proportionP1ZeroP1
75%	Strong	proportionP1ZeroP2
75%	Strong	proportionP1ZeroZero
75%	Strong	proportionZeroZeroZero
75%	Strong	proportionM1ZeroM1
75%	Strong	proportionP2ZeroP1
75%	Strong	proportionZeroZeroP1
75%	Strong	proportionP2ZeroP2
75%	Strong	proportionM2ZeroZero
75%	Strong	proportionM1ZeroP1
50%	Normal	proportionP2ZeroZero
50%	Normal	proportionZeroZeroM1
50%	Normal	proportionZeroZeroP2
50%	Normal	proportionM2ZeroM1
50%	Normal	proportionM2ZeroP1

proportionM2ZeroM1

90%	Very Strong	proportionP2ZeroP1
75%	Strong	proportionP2ZeroZero
75%	Strong	proportionP1ZeroP1
75%	Strong	proportionM2ZeroM2
75%	Strong	proportionM1ZeroM1
75%	Strong	proportionP2ZeroP2
75%	Strong	proportionP1ZeroZero
75%	Strong	proportionM2ZeroZero
50%	Normal	proportionM1ZeroM2
50%	Normal	proportionM1ZeroZero
50%	Normal	proportionP1ZeroP2
50%	Normal	proportionP1ZeroM1

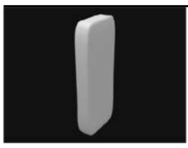
proportionM2ZeroM2

90%	Very Strong	proportionP2ZeroZero
75%	Strong	proportionP2ZeroP1
75%	Strong	proportionM1ZeroM2
75%	Strong	proportionP2ZeroM1
75%	Strong	proportionP1ZeroZero
75%	Strong	proportionM2ZeroM1
75%	Strong	proportionP1ZeroM1
50%	Normal	proportionP1ZeroP1
50%	Normal	proportionM1ZeroM1



proportionM2ZeroP1

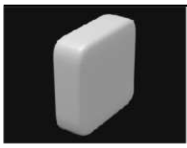
75%	Strong	proportionM2ZeroZero
75%	Strong	proportionM1ZeroP1
75%	Strong	proportionP2ZeroP2
75%	Strong	proportionP1ZeroP2
75%	Strong	proportionM2ZeroP2
50%	Normal	proportionM1ZeroZero
50%	Normal	proportionM1ZeroP2
50%	Normal	proportionP1ZeroP1



proportionM2ZeroP2

75%	Strong	proportionM2ZeroP1
75%	Strong	proportionM1ZeroP2
50%	Normal	proportionM1ZeroP1
50%	Normal	proportionP1ZeroP2

Classification Set: **Proportion** (Page 3/6)



proportionM2ZeroZero

- 90% Very Strong — proportionP2ZeroP2
- 75% Strong — proportionP2ZeroP1
- 75% Strong — proportionP1ZeroP2
- 75% Strong — proportionM1ZeroZero
- 75% Strong — proportionM2ZeroM1
- 75% Strong — proportionM2ZeroP1
- 75% Strong — proportionP1ZeroP1
- 50% Normal — proportionM1ZeroP1
- 50% Normal — proportionM1ZeroM1
- 50% Normal — proportionP1ZeroZero

proportionP1ZeroM1

- 90% Very Strong — proportionM1ZeroM2
- 75% Strong — proportionZeroZeroM2
- 75% Strong — proportionM1ZeroM1
- 75% Strong — proportionP1ZeroM2
- 75% Strong — proportionP2ZeroM1
- 75% Strong — proportionM2ZeroM2
- 75% Strong — proportionZeroZeroM1
- 75% Strong — proportionP1ZeroZero
- 50% Normal — proportionM2ZeroM1
- 50% Normal — proportionP2ZeroZero
- 50% Normal — proportionP2ZeroM2
- 50% Normal — proportionZeroZeroZero

proportionP1ZeroM2

- 75% Strong — proportionP2ZeroM2
- 75% Strong — proportionZeroZeroM2
- 75% Strong — proportionP1ZeroM1
- 75% Strong — proportionM1ZeroM2
- 50% Normal — proportionP2ZeroM1
- 50% Normal — proportionZeroZeroM1

proportionP1ZeroP1

- 90% Very Strong — proportionM1ZeroZero
- 75% Strong — proportionM2ZeroZero
- 75% Strong — proportionZeroZeroZero
- 75% Strong — proportionP1ZeroZero
- 75% Strong — proportionP2ZeroP1
- 75% Strong — proportionM1ZeroM1
- 75% Strong — proportionM1ZeroP1
- 75% Strong — proportionM2ZeroM1
- 75% Strong — proportionP1ZeroP2
- 75% Strong — proportionZeroZeroP1
- 50% Normal — proportionP2ZeroP2
- 50% Normal — proportionM2ZeroP1
- 50% Normal — proportionP2ZeroZero
- 50% Normal — proportionZeroZeroM1
- 50% Normal — proportionM2ZeroM2
- 50% Normal — proportionZeroZeroP2

Classification Set: **Proportion** (Page 4/6)

proportionP1ZeroP2

90%	Very Strong	proportionM1ZeroP1
75%	Strong	proportionP2ZeroP2
75%	Strong	proportionM1ZeroP2
75%	Strong	proportionP1ZeroP1
75%	Strong	proportionM2ZeroP1
75%	Strong	proportionZeroZeroP1
75%	Strong	proportionM1ZeroZero
75%	Strong	proportionM2ZeroZero
75%	Strong	proportionZeroZeroP2
50%	Normal	proportionZeroZeroZero
50%	Normal	proportionP2ZeroP1
50%	Normal	proportionM2ZeroP2
50%	Normal	proportionM2ZeroM1

proportionP1ZeroZero

90%	Very Strong	proportionM1ZeroM1
75%	Strong	proportionM1ZeroZero
75%	Strong	proportionP2ZeroZero
75%	Strong	proportionZeroZeroM1
75%	Strong	proportionM2ZeroM1
75%	Strong	proportionP1ZeroM1
75%	Strong	proportionM1ZeroM2
75%	Strong	proportionZeroZeroZero
75%	Strong	proportionP1ZeroP1
75%	Strong	proportionM2ZeroM2
50%	Normal	proportionP2ZeroP1
50%	Normal	proportionZeroZeroM2
50%	Normal	proportionP2ZeroM1
50%	Normal	proportionM2ZeroZero
50%	Normal	proportionZeroZeroP1

proportionP2ZeroM1

75%	Strong	proportionP2ZeroM2
75%	Strong	proportionM1ZeroM2
75%	Strong	proportionP2ZeroZero
75%	Strong	proportionM2ZeroM2
75%	Strong	proportionP1ZeroM1
50%	Normal	proportionP1ZeroM2
50%	Normal	proportionM1ZeroM1
50%	Normal	proportionP1ZeroZero

proportionP2ZeroM2

75%	Strong	proportionP2ZeroM1
75%	Strong	proportionP1ZeroM2
50%	Normal	proportionP1ZeroM1
50%	Normal	proportionM1ZeroM2

Classification Set: **Proportion** (Page 5/6)

proportionP2ZeroP1

90% Very Strong proportionM2ZeroM1	75% Strong proportionM2ZeroM2	75% Strong proportionM2ZeroZero	75% Strong proportionM1ZeroM1
75% Strong proportionP2ZeroZero	75% Strong proportionP2ZeroP2	75% Strong proportionM1ZeroZero	75% Strong proportionP1ZeroP1
50% Normal proportionM1ZeroM2	50% Normal proportionP1ZeroP2	50% Normal proportionM1ZeroP1	50% Normal proportionP1ZeroZero

proportionP2ZeroP2

90% Very Strong proportionM2ZeroZero	75% Strong proportionM2ZeroP1	75% Strong proportionM2ZeroM1	75% Strong proportionP2ZeroP1
75% Strong proportionM1ZeroZero	75% Strong proportionP1ZeroP2	75% Strong proportionM1ZeroP1	50% Normal proportionM1ZeroM1
50% Normal proportionP1ZeroP1			

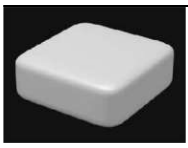
proportionP2ZeroZero

90% Very Strong proportionM2ZeroM2	75% Strong proportionM2ZeroM1	75% Strong proportionM1ZeroM2	75% Strong proportionP2ZeroM1
75% Strong proportionP1ZeroZero	75% Strong proportionM1ZeroM1	75% Strong proportionP2ZeroP1	50% Normal proportionP1ZeroM1
50% Normal proportionM1ZeroZero	50% Normal proportionP1ZeroP1		

proportionZeroZeroM1

75% Strong proportionZeroZeroM2	75% Strong proportionP1ZeroM1	75% Strong proportionZeroZeroZero	75% Strong proportionP1ZeroZero
75% Strong proportionM1ZeroM2	75% Strong proportionM1ZeroM1	50% Normal proportionP1ZeroM2	50% Normal proportionP1ZeroP1
50% Normal proportionM1ZeroZero			

Classification Set: **Proportion** (Page 6/6)



proportionZeroZeroM2

 75% Strong proportionP1ZeroM2

 75% Strong proportionZeroZeroM1

 75% Strong proportionP1ZeroM1

 75% Strong proportionM1ZeroM2

 50% Normal proportionP1ZeroZero

 50% Normal proportionM1ZeroM1

proportionZeroZeroP1

 75% Strong proportionZeroZeroZero

 75% Strong proportionP1ZeroP1

 75% Strong proportionZeroZeroP2

 75% Strong proportionP1ZeroP2

 75% Strong proportionM1ZeroZero

 75% Strong proportionM1ZeroP1

 50% Normal proportionP1ZeroZero

 50% Normal proportionM1ZeroP2

 50% Normal proportionM1ZeroM1

proportionZeroZeroP2

 75% Strong proportionZeroZeroP1

 75% Strong proportionP1ZeroP2

 75% Strong proportionM1ZeroP2

 75% Strong proportionM1ZeroP1

 50% Normal proportionP1ZeroP1

 50% Normal proportionM1ZeroZero

proportionZeroZeroZero

 75% Strong proportionZeroZeroM1

 75% Strong proportionP1ZeroZero

 75% Strong proportionP1ZeroP1

 75% Strong proportionM1ZeroZero

 75% Strong proportionM1ZeroM1

 75% Strong proportionZeroZeroP1

 50% Normal proportionP1ZeroM1

 50% Normal proportionP1ZeroP2

 50% Normal proportionM1ZeroP1

 50% Normal proportionM1ZeroM2

This page intentionally left blank in print layout

Appendix C

Empirical Data
Per Project

part of doctoral thesis

Building Shape Classification

Philipp Jurewicz 2023

Note about image references:

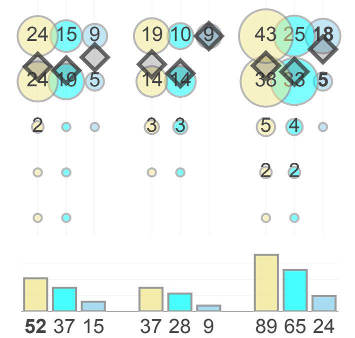
This appendix is part of the doctoral thesis "Building Shape Classification" at TU Wien. This appendix contains 80 photographs of World Exposition pavilions. Please also see the chapter "18. Image References" in the main document to understand the methodology. The section titled "80 Default Photographs of the 80 World Exposition Pavilions" in chapter 18 covers the photographs used in this appendix.

A1 - Expo 2010 Canada Pavilion (Shanghai)

(page 1/2)

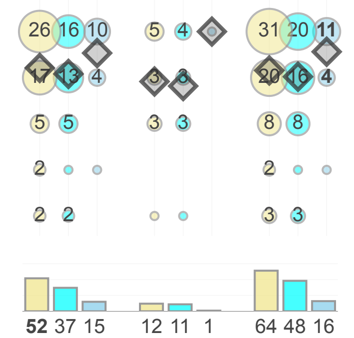
4.33(mean) A2 emp-n-de10

	1st			2nd			both		
Ø	**4.33**	4.2	4.5	4.4	4.2	5.0	4.3	4.2	4.7
σ	**0.81**	0.9	0.6	0.8	0.8	0.0	0.8	0.8	0.6
σ²	**0.66**	0.7	0.4	0.6	0.6	0.0	0.6	0.7	0.3



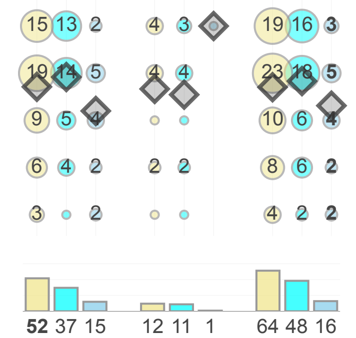
4.21(mean) A6 emp-n-pt

	1st			2nd			both		
Ø	**4.21**	4.1	4.5	3.9	3.8	5.0	4.2	4.0	4.6
σ	**1.04**	1.1	0.8	1.2	1.3	0.0	1.1	1.1	0.8
σ²	**1.07**	1.2	0.7	1.5	1.6	0.0	1.1	1.3	0.7



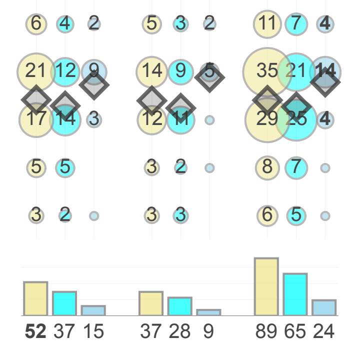
3.71(mean) A5 emp-n-ve

	1st			2nd			both		
Ø	**3.71**	3.9	3.2	3.7	3.5	5.0	3.7	3.8	3.3
σ	**1.18**	1.1	1.3	1.4	1.4	0.0	1.2	1.2	1.3
σ²	**1.39**	1.2	1.6	1.9	1.9	0.0	1.5	1.3	1.7



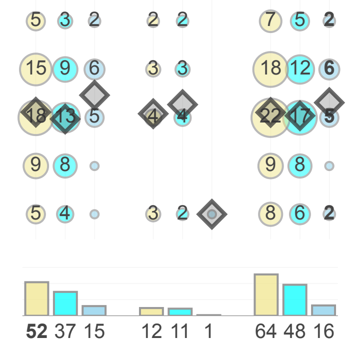
3.42(mean) A3 g-europe

	1st			2nd			both		
Ø	**3.42**	3.3	3.7	3.4	3.3	3.9	3.4	3.3	3.8
σ	**1.02**	1.0	1.0	1.1	1.1	0.9	1.0	1.1	0.9
σ²	**1.03**	1.0	0.9	1.2	1.2	0.9	1.1	1.1	0.9



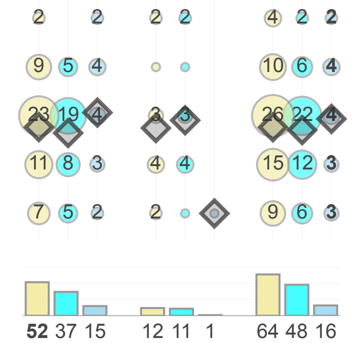
3.12(mean) A7 emp-n-pl

	1st			2nd			both		
Ø	**3.12**	3.0	3.5	3.1	3.3	1.0	3.1	3.0	3.3
σ	**1.11**	1.1	1.1	1.4	1.3	0.0	1.2	1.2	1.2
σ²	**1.24**	1.2	1.1	2.1	1.8	0.0	1.4	1.4	1.4



2.77(mean) A4 emp-n-ru

	1st			2nd			both		
Ø	**2.77**	2.6	3.1	2.8	2.9	1.0	2.8	2.7	2.9
σ	**1.02**	0.9	1.3	1.4	1.3	0.0	1.1	1.0	1.3
σ²	**1.04**	0.8	1.6	1.8	1.7	0.0	1.2	1.0	1.8

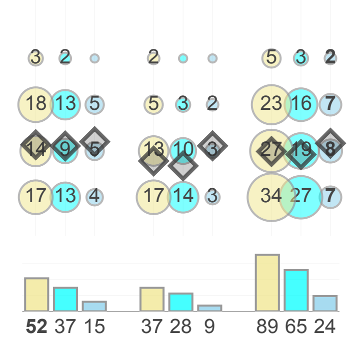


A1 - Expo 2010 Canada Pavilion (Shanghai)

(page 2/2)

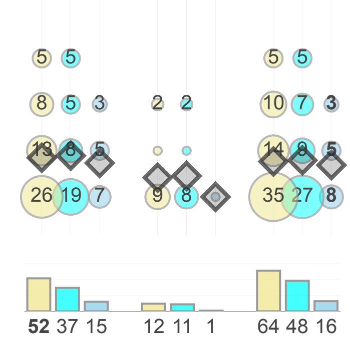
2.13(mean) D1 emp-r-ont

	1st			2nd			both		
Ø	**2.13**	2.1	2.2	1.8	1.7	2.1	2.0	1.9	2.2
σ	**0.95**	1.0	0.9	0.9	0.8	1.1	0.9	0.9	1.0
$σ^2$	**0.90**	0.9	0.9	0.8	0.7	1.1	0.9	0.9	0.9



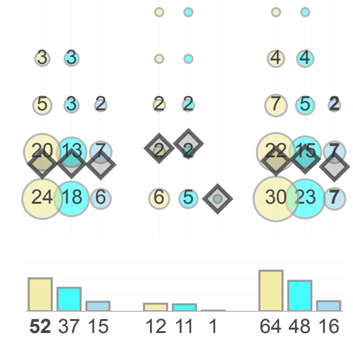
1.85(mean) C1 emp-n-ao

	1st			2nd			both		
Ø	**1.85**	1.9	1.7	1.4	1.5	1.0	1.8	1.8	1.7
σ	**1.02**	1.1	0.8	0.8	0.8	0.0	1.0	1.1	0.8
$σ^2$	**1.03**	1.2	0.6	0.6	0.7	0.0	1.0	1.1	0.6



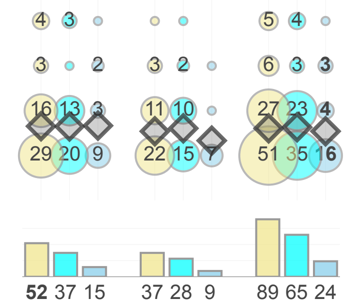
1.75(mean) B2 emp-n-uk

	1st			2nd			both		
Ø	**1.75**	1.8	1.7	2.1	2.2	1.0	1.8	1.9	1.7
σ	**0.86**	0.9	0.7	1.4	1.4	0.0	1.0	1.1	0.7
$σ^2$	**0.74**	0.9	0.5	1.9	2.0	0.0	0.9	1.1	0.5



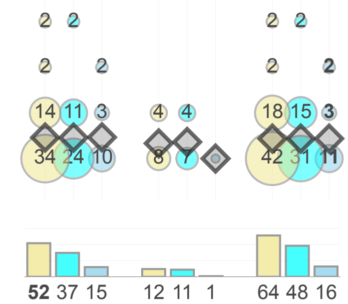
1.65(mean) B1 emp-n-su70

	1st			2nd			both		
Ø	**1.65**	1.6	1.7	1.5	1.6	1.3	1.6	1.6	1.5
σ	**0.91**	0.9	1.0	0.8	0.8	0.7	0.8	0.8	0.9
$σ^2$	**0.82**	0.8	1.0	0.6	0.6	0.5	0.7	0.7	0.8



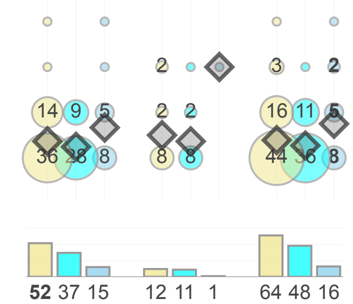
1.46(mean) B3 emp-n-ph

	1st			2nd			both		
Ø	**1.46**	1.5	1.5	1.3	1.4	1.0	1.4	1.4	1.4
σ	**0.75**	0.8	0.7	0.5	0.5	0.0	0.7	0.7	0.7
$σ^2$	**0.57**	0.6	0.6	0.2	0.3	0.0	0.5	0.5	0.5



1.37(mean) C2 emp-n-dz

	1st			2nd			both		
Ø	**1.37**	1.2	1.7	1.5	1.4	3.0	1.4	1.3	1.8
σ	**0.63**	0.4	0.9	0.8	0.7	0.0	0.7	0.5	0.9
$σ^2$	**0.39**	0.2	0.8	0.6	0.5	0.0	0.4	0.2	0.9

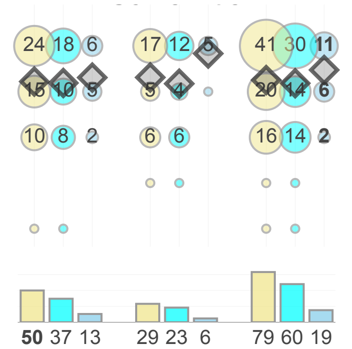


A2 - Expo 2010 Germany Pavilion (Shanghai)

(page 1/2)

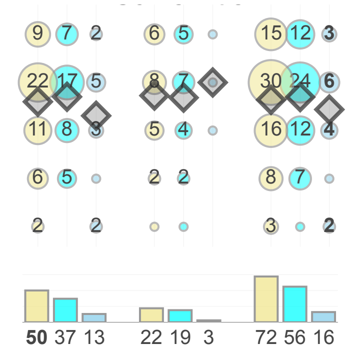
4.22(mean) A6 emp-n-pt

	1st			2nd			both		
Ø	**4.22**	4.2	4.3	4.3	4.2	4.8	4.3	4.2	4.5
σ	**0.91**	1.0	0.8	0.9	1.0	0.4	0.9	1.0	0.7
σ^2	**0.83**	0.9	0.6	0.9	1.0	0.2	0.8	0.9	0.5



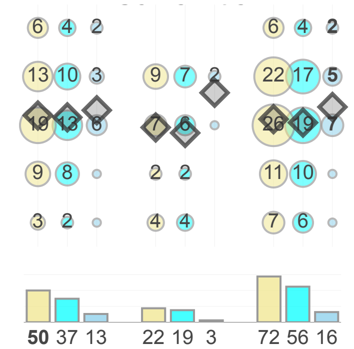
3.60(mean) A5 emp-n-ve

	1st			2nd			both		
Ø	**3.60**	3.7	3.3	3.7	3.7	4.0	3.6	3.7	3.4
σ	**1.05**	0.9	1.3	1.1	1.2	1.0	1.1	1.0	1.3
σ^2	**1.10**	0.9	1.7	1.3	1.3	1.0	1.1	1.0	1.6



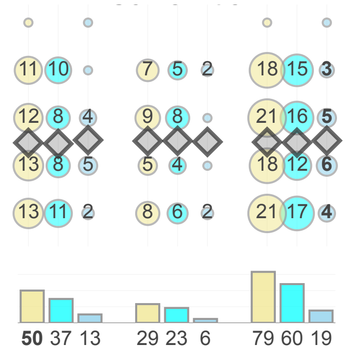
3.20(mean) A7 emp-n-pl

	1st			2nd			both		
Ø	**3.20**	3.2	3.3	3.0	2.8	3.7	3.1	3.1	3.4
σ	**1.07**	1.1	1.1	1.1	1.2	0.6	1.1	1.1	1.0
σ^2	**1.14**	1.1	1.2	1.3	1.4	0.3	1.2	1.2	1.1



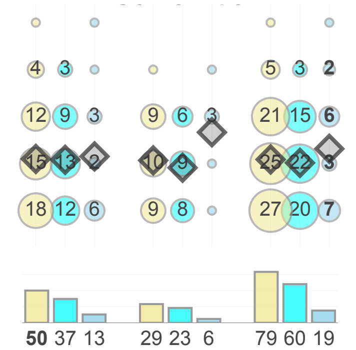
2.48(mean) A4 emp-n-ru

	1st			2nd			both		
Ø	**2.48**	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
σ	**1.16**	1.2	1.1	1.2	1.1	1.4	1.2	1.2	1.2
σ^2	**1.36**	1.4	1.3	1.3	1.3	1.9	1.3	1.3	1.4



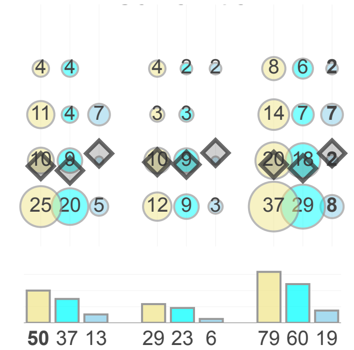
2.10(mean) B2 emp-n-uk

	1st			2nd			both		
Ø	**2.10**	2.1	2.2	2.1	1.9	2.7	2.1	2.0	2.3
σ	**1.05**	1.0	1.3	0.9	0.8	1.0	1.0	0.9	1.2
σ^2	**1.11**	0.9	1.8	0.8	0.6	1.1	1.0	0.8	1.6



1.88(mean) D2 g-africa

	1st			2nd			both		
Ø	**1.88**	1.8	2.2	2.0	1.9	2.2	1.9	1.8	2.2
σ	**1.02**	1.0	1.0	1.1	0.9	1.5	1.0	1.0	1.1
σ^2	**1.05**	1.1	1.0	1.1	0.9	2.2	1.1	1.0	1.3

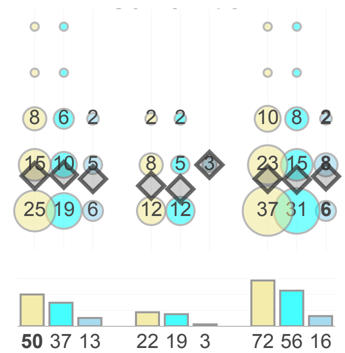


A2 - Expo 2010 Germany Pavilion (Shanghai)

(page 2/2)

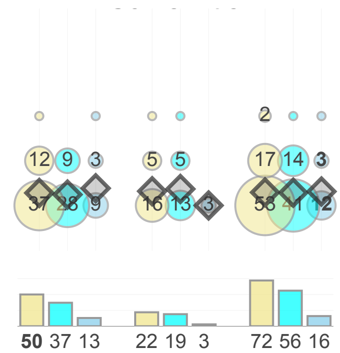
1.76(mean) B3 emp-n-ph

	1st			2nd			both		
Ø	**1.76**	1.8	1.7	1.5	1.5	2.0	1.7	1.7	1.8
σ	**0.94**	1.0	0.8	0.7	0.7	0.0	0.9	0.9	0.7
σ²	**0.88**	1.0	0.6	0.5	0.5	0.0	0.8	0.8	0.5



1.28(mean) D3 emp-c-pulp

	1st			2nd			both		
Ø	**1.28**	1.2	1.4	1.3	1.4	1.0	1.3	1.3	1.3
σ	**0.50**	0.4	0.7	0.6	0.6	0.0	0.5	0.5	0.6
σ²	**0.25**	0.2	0.4	0.3	0.4	0.0	0.3	0.2	0.4

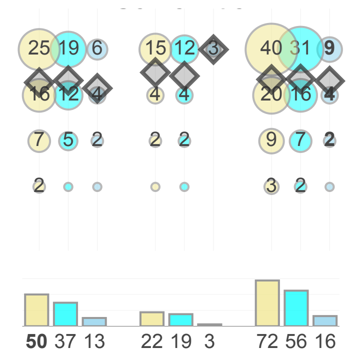


A3 - Expo 1967 Europe Pavilion (Montreal)

(page 1/2)

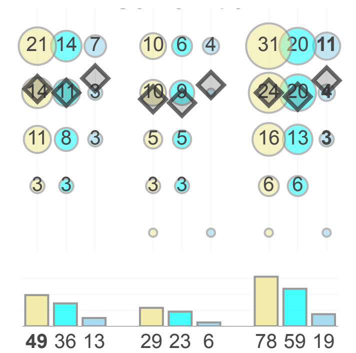
4.28(mean) A6 emp-n-pt

	1st			2nd			both		
Ø	**4.28**	4.3	4.2	4.5	4.4	5.0	4.3	4.4	4.3
σ	**0.86**	0.8	1.0	0.9	0.9	0.0	0.9	0.8	0.9
σ²	**0.74**	0.7	1.0	0.7	0.8	0.0	0.7	0.7	0.9



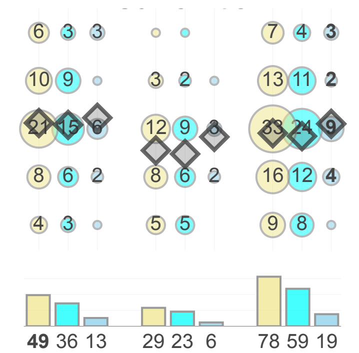
4.08(mean) A2 emp-n-de10

	1st			2nd			both		
Ø	**4.08**	4.0	4.3	3.9	3.8	4.2	4.0	3.9	4.3
σ	**0.95**	1.0	0.9	1.1	1.0	1.6	1.0	1.0	1.1
σ²	**0.91**	1.0	0.7	1.3	1.0	2.6	1.0	1.0	1.2



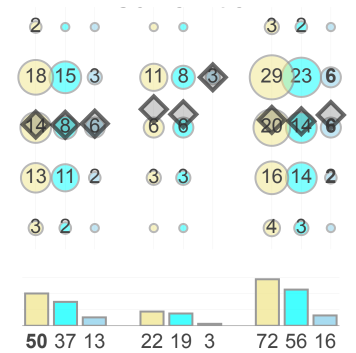
3.12(mean) A7 emp-n-pl

	1st			2nd			both		
Ø	**3.12**	3.1	3.2	2.6	2.5	2.8	2.9	2.8	3.1
σ	**1.09**	1.1	1.2	1.0	1.1	0.8	1.1	1.1	1.1
σ²	**1.19**	1.1	1.5	1.0	1.2	0.6	1.2	1.2	1.2



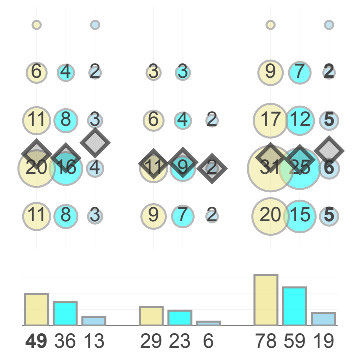
3.06(mean) A5 emp-n-ve

	1st			2nd			both		
Ø	**3.06**	3.1	3.1	3.4	3.3	4.0	3.2	3.1	3.3
σ	**1.02**	1.0	1.0	1.0	1.0	0.0	1.0	1.0	1.0
σ²	**1.04**	1.1	1.1	0.9	1.0	0.0	1.0	1.0	1.0



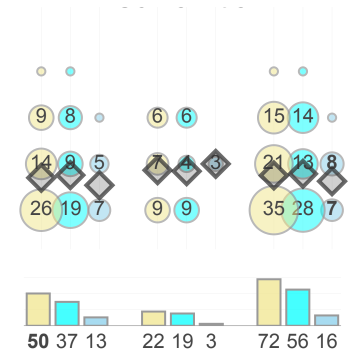
2.31(mean) A4 emp-n-ru

	1st			2nd			both		
Ø	**2.31**	2.2	2.5	2.1	2.1	2.0	2.2	2.2	2.4
σ	**1.02**	0.9	1.3	1.0	1.0	0.9	1.0	1.0	1.2
σ²	**1.05**	0.9	1.6	1.0	1.0	0.8	1.0	0.9	1.4



1.70(mean) B3 emp-n-ph

	1st			2nd			both		
Ø	**1.70**	1.8	1.5	1.9	1.8	2.0	1.8	1.8	1.6
σ	**0.84**	0.9	0.7	0.8	0.9	0.0	0.8	0.9	0.6
σ²	**0.70**	0.8	0.4	0.7	0.8	0.0	0.7	0.8	0.4

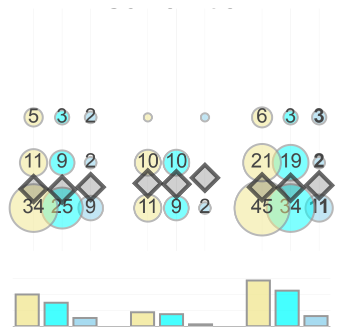


A3 - Expo 1967 Europe Pavilion (Montreal)

(page 2/2)

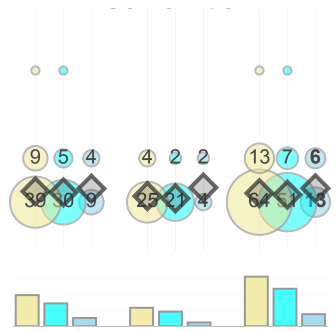
1.42(mean) D3 emp-c-pulp

		1st			2nd			both		
Ø	**1.42**	1.4	1.5	1.5	1.5	1.7	1.5	1.4	1.5	
σ	**0.67**	0.6	0.8	0.6	0.5	1.2	0.6	0.6	0.8	
σ^2	**0.45**	0.4	0.6	0.4	0.3	1.3	0.4	0.4	0.7	



1.24(mean) C2 emp-n-dz

		1st			2nd			both		
Ø	**1.24**	1.2	1.3	1.1	1.1	1.3	1.2	1.2	1.3	
σ	**0.56**	0.6	0.5	0.4	0.3	0.5	0.5	0.5	0.5	
σ^2	**0.31**	0.3	0.2	0.1	0.1	0.3	0.2	0.2	0.2	

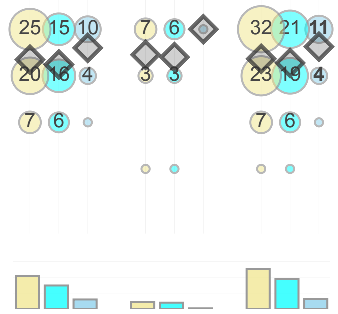


B1 - Expo 1970 Soviet Union Pavilion (Osaka)

(page 1/2)

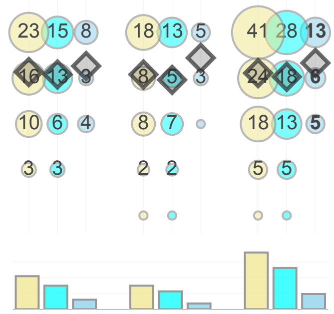
4.35(mean) B7 c-philips

	1st			2nd			both		
Ø	**4.35**	4.2	4.6	4.5	4.4	5.0	4.4	4.3	4.6
σ	**0.71**	0.7	0.6	0.9	1.0	0.0	0.7	0.8	0.6
σ²	**0.51**	0.5	0.4	0.9	0.9	0.0	0.6	0.6	0.4



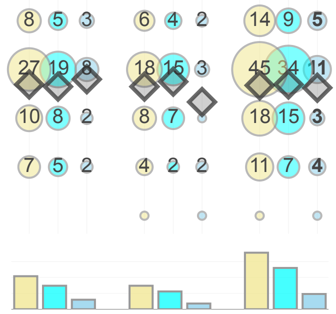
4.13(mean) B3 emp-n-ph

	1st			2nd			both		
Ø	**4.13**	4.1	4.3	4.1	4.0	4.4	4.1	4.0	4.3
σ	**0.93**	1.0	0.9	1.1	1.2	0.7	1.0	1.0	0.8
σ²	**0.86**	0.9	0.8	1.2	1.4	0.5	1.0	1.1	0.7



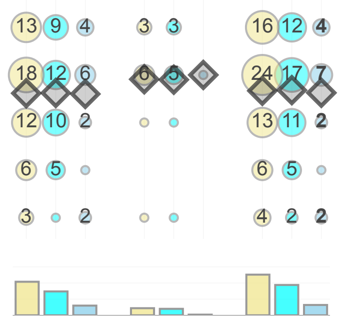
3.69(mean) B2 emp-n-uk

	1st			2nd			both		
Ø	**3.69**	3.6	3.8	3.6	3.8	3.3	3.7	3.7	3.6
σ	**0.90**	0.9	0.9	1.0	0.8	1.4	0.9	0.8	1.1
σ²	**0.81**	0.8	0.9	1.0	0.6	2.0	0.9	0.7	1.3



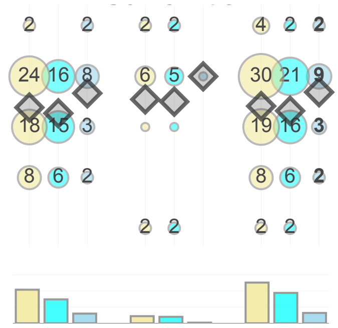
3.62(mean) B5 emp-n-lu

	1st			2nd			both		
Ø	**3.62**	3.6	3.6	3.9	3.9	4.0	3.7	3.7	3.6
σ	**1.16**	1.1	1.4	1.1	1.2	0.0	1.2	1.1	1.3
σ²	**1.34**	1.2	1.8	1.3	1.4	0.0	1.3	1.2	1.7



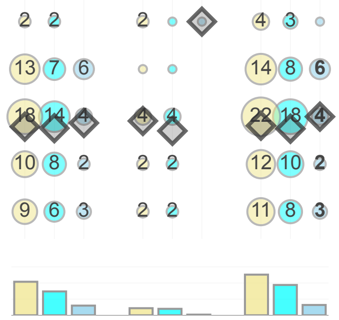
3.38(mean) B6 c-civil

	1st			2nd			both		
Ø	**3.38**	3.3	3.7	3.5	3.5	4.0	3.4	3.3	3.7
σ	**0.80**	0.7	0.9	1.4	1.4	0.0	0.9	0.9	0.9
σ²	**0.63**	0.5	0.8	1.9	2.1	0.0	0.8	0.8	0.8



2.79(mean) B4 emp-n-my

	1st			2nd			both		
Ø	**2.79**	2.8	2.9	2.9	2.7	5.0	2.8	2.7	3.0
σ	**1.13**	1.1	1.2	1.4	1.3	0.0	1.2	1.1	1.3
σ²	**1.27**	1.2	1.4	1.9	1.6	0.0	1.4	1.3	1.6

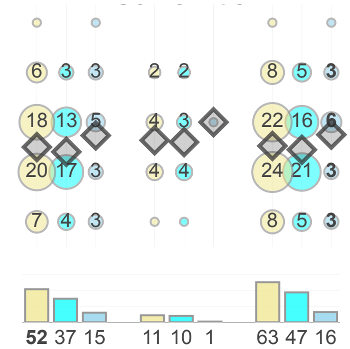


B1 - Expo 1970 Soviet Union Pavilion (Osaka)

(page 2/2)

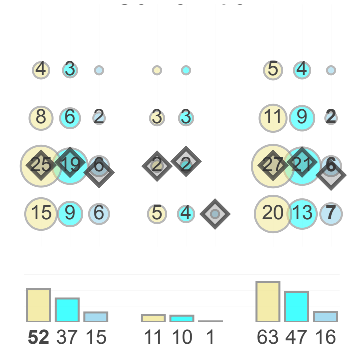
2.50(mean) D1 emp-r-ont

	1st			2nd			both		
Ø	**2.50**	2.4	2.7	2.6	2.6	3.0	2.5	2.4	2.8
σ	**0.94**	0.8	1.2	0.9	1.0	0.0	0.9	0.8	1.2
σ²	**0.88**	0.6	1.5	0.9	0.9	0.0	0.9	0.7	1.4



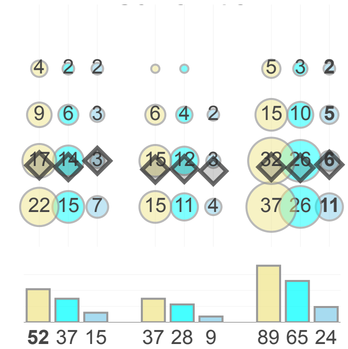
2.02(mean) C3 emp-n-fr67

	1st			2nd			both		
Ø	**2.02**	2.1	1.9	2.0	2.1	1.0	2.0	2.1	1.8
σ	**0.87**	0.9	0.9	1.1	1.1	0.0	0.9	0.9	0.9
σ²	**0.76**	0.7	0.8	1.2	1.2	0.0	0.8	0.8	0.8



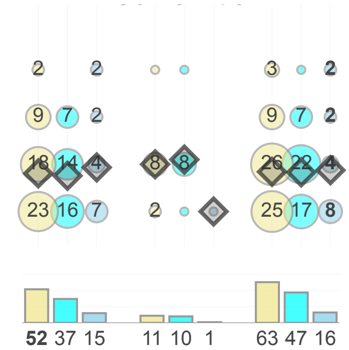
1.90(mean) A1 emp-n-ca10

	1st			2nd			both		
Ø	**1.90**	1.9	2.0	1.8	1.8	1.8	1.9	1.8	1.9
σ	**0.96**	0.9	1.1	0.8	0.8	0.8	0.9	0.9	1.0
σ²	**0.91**	0.8	1.3	0.7	0.7	0.7	0.8	0.7	1.0



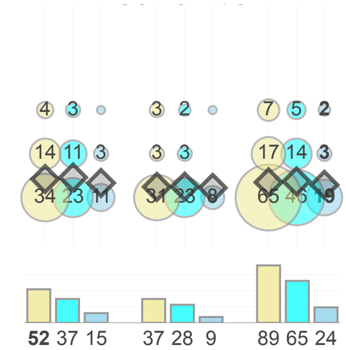
1.81(mean) D2 g-africa

	1st			2nd			both		
Ø	**1.81**	1.8	1.9	2.0	2.1	1.0	1.8	1.8	1.9
σ	**0.86**	0.8	1.1	0.8	0.7	0.0	0.8	0.8	1.1
σ²	**0.75**	0.6	1.2	0.6	0.5	0.0	0.7	0.6	1.2



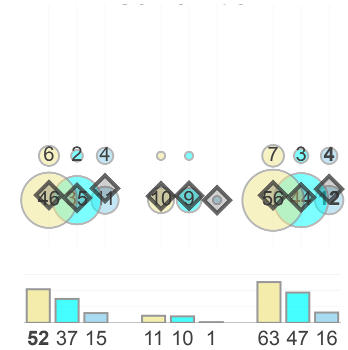
1.42(mean) C1 emp-n-ao

	1st			2nd			both		
Ø	**1.42**	1.5	1.3	1.2	1.3	1.2	1.3	1.4	1.3
σ	**0.64**	0.6	0.6	0.6	0.6	0.7	0.6	0.6	0.6
σ²	**0.41**	0.4	0.4	0.4	0.3	0.4	0.4	0.4	0.4



1.12(mean) C2 emp-n-dz

	1st			2nd			both		
Ø	**1.12**	1.1	1.3	1.1	1.1	1.0	1.1	1.1	1.3
σ	**0.32**	0.2	0.5	0.3	0.3	0.0	0.3	0.2	0.4
σ²	**0.10**	0.1	0.2	0.1	0.1	0.0	0.1	0.1	0.2

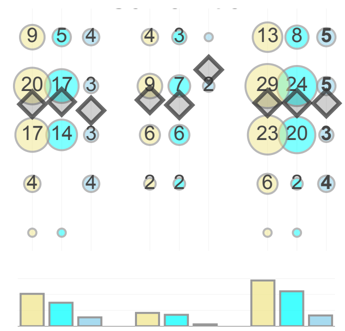


B2 - Expo 1967 United Kingdom Pavilion (Montreal)

(page 1/2)

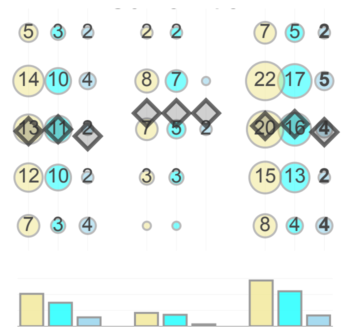
3.63(mean) B5 emp-n-lu

	1st			2nd			both		
Ø	**3.63**	3.7	3.5	3.7	3.6	4.3	3.7	3.7	3.6
σ	**0.94**	0.8	1.2	0.9	0.9	0.6	0.9	0.8	1.2
$σ^2$	**0.88**	0.7	1.5	0.8	0.8	0.3	0.8	0.7	1.4



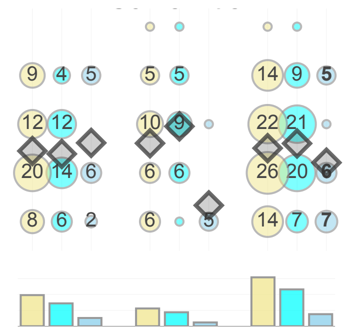
2.96(mean) B7 c-philips

	1st			2nd			both		
Ø	**2.96**	3.0	2.9	3.3	3.3	3.3	3.1	3.1	2.9
σ	**1.22**	1.1	1.5	1.0	1.1	0.6	1.2	1.1	1.4
$σ^2$	**1.48**	1.2	2.3	1.0	1.2	0.3	1.4	1.2	1.9



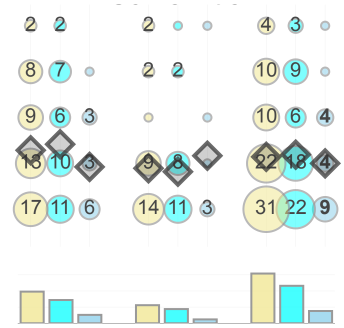
2.45(mean) B6 c-civil

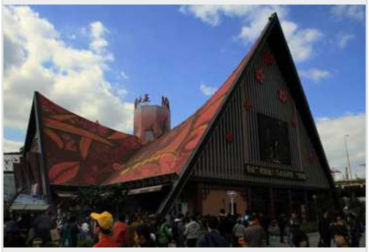
	1st			2nd			both		
Ø	**2.45**	2.4	2.6	2.6	3.0	1.3	2.5	2.6	2.2
σ	**0.98**	0.9	1.2	1.1	1.0	0.8	1.0	1.0	1.2
$σ^2$	**0.96**	0.8	1.4	1.3	0.9	0.7	1.1	0.9	1.5



2.29(mean) A4 emp-n-ru

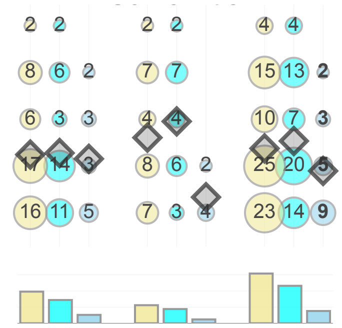
	1st			2nd			both		
Ø	**2.29**	2.4	1.9	1.9	1.8	2.2	2.1	2.2	2.0
σ	**1.22**	1.3	1.0	1.2	1.1	1.6	1.2	1.2	1.2
$σ^2$	**1.50**	1.6	1.1	1.5	1.3	2.6	1.5	1.6	1.4

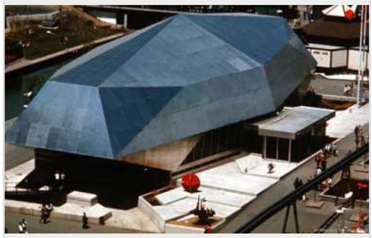




2.24(mean) B4 emp-n-my

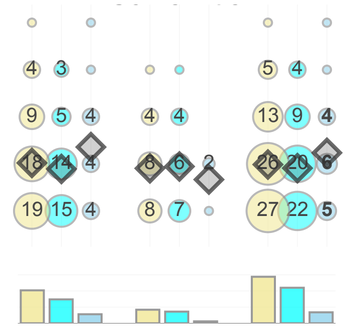
	1st			2nd			both		
Ø	**2.24**	2.3	2.2	2.6	3.0	1.3	2.4	2.5	1.9
σ	**1.20**	1.2	1.1	1.3	1.3	0.5	1.2	1.3	1.0
$σ^2$	**1.44**	1.5	1.3	1.7	1.6	0.3	1.6	1.6	1.1





2.02(mean) A3 g-europe

	1st			2nd			both		
Ø	**2.02**	1.9	2.4	1.9	1.9	1.7	2.0	1.9	2.2
σ	**1.03**	0.9	1.2	0.9	0.9	0.6	1.0	0.9	1.1
$σ^2$	**1.06**	0.9	1.5	0.8	0.9	0.3	1.0	0.9	1.3

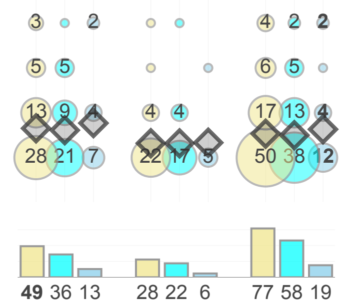


B2 - Expo 1967 United Kingdom Pavilion (Montreal)

(page 2/2)

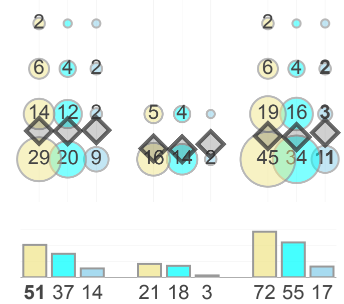
1.65(mean) C2 emp-n-dz

	1st			2nd			both		
Ø	**1.65**	1.6	1.8	1.3	1.3	1.3	1.5	1.5	1.6
σ	**0.90**	0.8	1.1	0.7	0.7	0.8	0.9	0.8	1.0
σ^2	**0.81**	0.7	1.2	0.5	0.5	0.7	0.7	0.6	1.0



1.63(mean) C3 emp-n-fr67

	1st			2nd			both		
Ø	**1.63**	1.6	1.6	1.2	1.2	1.3	1.5	1.5	1.6
σ	**0.85**	0.8	1.0	0.4	0.4	0.6	0.8	0.7	0.9
σ^2	**0.72**	0.6	1.0	0.2	0.2	0.3	0.6	0.5	0.9

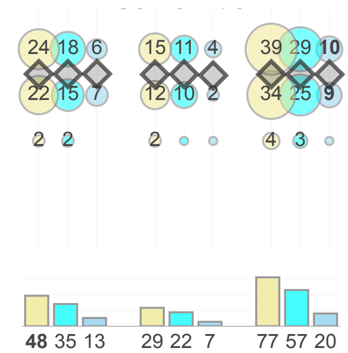


B3 - Expo 1970 Philippines Pavilion (Osaka)

(page 1/2)

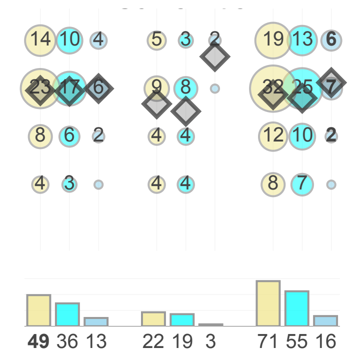
4.46(mean) B7 c-philips

	1st			2nd			both		
Ø	**4.46**	4.5	4.5	4.4	4.5	4.4	4.5	4.5	4.5
σ	**0.58**	0.6	0.5	0.6	0.6	0.8	0.6	0.6	0.6
σ²	**0.34**	0.4	0.3	0.4	0.4	0.6	0.4	0.4	0.4



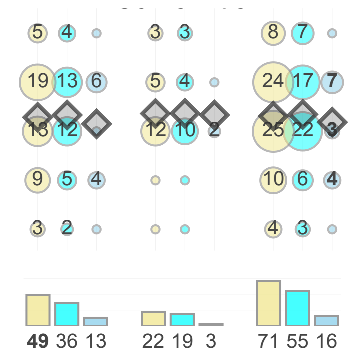
3.96(mean) B6 c-civil

	1st			2nd			both		
Ø	**3.96**	3.9	4.0	3.7	3.5	4.7	3.9	3.8	4.1
σ	**0.89**	0.9	0.9	1.0	1.0	0.6	0.9	1.0	0.9
σ²	**0.79**	0.8	0.8	1.1	1.0	0.3	0.9	0.9	0.8



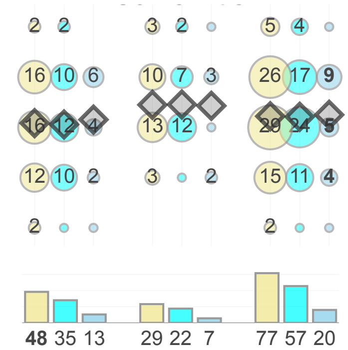
3.29(mean) B5 emp-n-lu

	1st			2nd			both		
Ø	**3.29**	3.3	3.2	3.4	3.4	3.3	3.3	3.3	3.2
σ	**1.08**	1.0	1.2	1.0	1.0	0.6	1.0	1.0	1.1
σ²	**1.17**	1.1	1.5	0.9	1.0	0.3	1.1	1.0	1.2



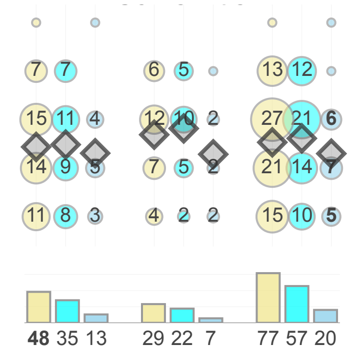
3.08(mean) B4 emp-n-my

	1st			2nd			both		
Ø	**3.08**	3.1	3.2	3.4	3.5	3.4	3.2	3.2	3.3
σ	**0.96**	1.0	1.0	0.8	0.7	1.1	0.9	0.9	1.0
σ²	**0.93**	0.9	1.0	0.7	0.5	1.3	0.9	0.8	1.0



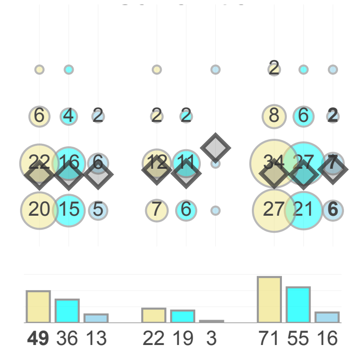
2.44(mean) B2 emp-n-uk

	1st			2nd			both		
Ø	**2.44**	2.5	2.3	2.7	2.8	2.3	2.5	2.6	2.3
σ	**1.07**	1.1	1.1	1.0	0.9	1.1	1.0	1.0	1.1
σ²	**1.14**	1.1	1.2	0.9	0.8	1.2	1.1	1.0	1.2



1.76(mean) A5 emp-n-ve

	1st			2nd			both		
Ø	**1.76**	1.8	1.8	1.9	1.8	2.3	1.8	1.8	1.9
σ	**0.75**	0.8	0.7	0.8	0.6	1.5	0.8	0.7	0.9
σ²	**0.56**	0.6	0.5	0.6	0.4	2.3	0.6	0.5	0.8

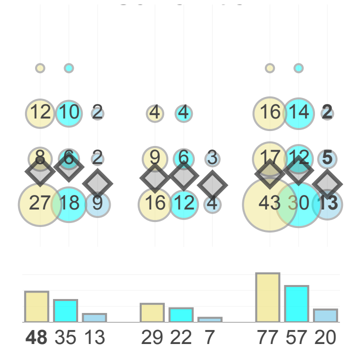


B3 - Expo 1970 Philippines Pavilion (Osaka)

(page 2/2)

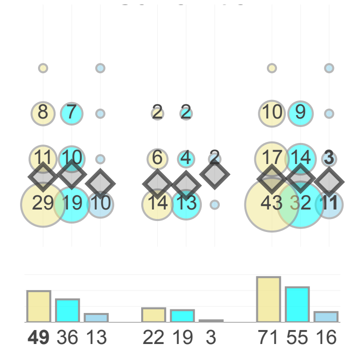
1.73(mean) D2 g-africa

	1st			2nd			both		
Ø	**1.73**	1.8	1.5	1.6	1.6	1.4	1.7	1.8	1.5
σ	**0.92**	1.0	0.8	0.7	0.8	0.5	0.8	0.9	0.7
σ²	**0.84**	0.9	0.6	0.5	0.6	0.3	0.7	0.8	0.5



1.61(mean) C3 emp-n-fr67

	1st			2nd			both		
Ø	**1.61**	1.7	1.5	1.5	1.4	1.7	1.6	1.6	1.5
σ	**0.84**	0.8	1.0	0.7	0.7	0.6	0.8	0.8	0.9
σ²	**0.70**	0.6	0.9	0.5	0.5	0.3	0.6	0.6	0.8

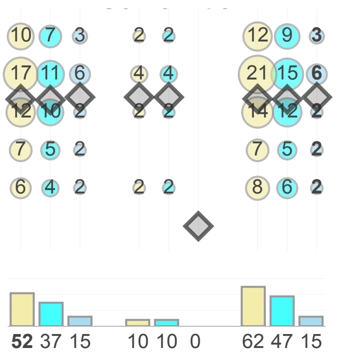


C1 - Expo 2010 Angola Pavilion (Shanghai)

(page 1/2)

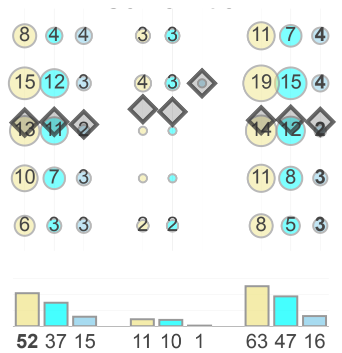
3.35(mean) C6 emp-n-hr

	1st			2nd			both		
Ø	**3.35**	3.3	3.4	3.4	3.4	0.0	3.4	3.3	3.4
σ	**1.27**	1.2	1.4	1.4	1.4	0.0	1.3	1.3	1.4
σ²	**1.60**	1.6	1.8	2.0	2.0	0.0	1.6	1.6	1.8



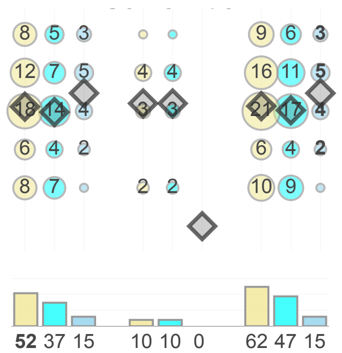
3.17(mean) C4 emp-n-mc

	1st			2nd			both		
Ø	**3.17**	3.2	3.1	3.5	3.4	4.0	3.2	3.2	3.2
σ	**1.25**	1.1	1.6	1.5	1.6	0.0	1.3	1.2	1.5
σ²	**1.56**	1.3	2.4	2.3	2.5	0.0	1.7	1.5	2.3



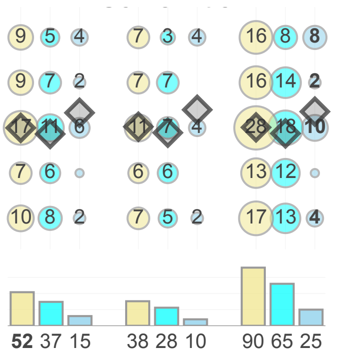
3.12(mean) C7 emp-n-lk

	1st			2nd			both		
Ø	**3.12**	3.0	3.5	3.2	3.2	0.0	3.1	3.0	3.5
σ	**1.26**	1.3	1.2	1.3	1.3	0.0	1.3	1.3	1.2
σ²	**1.59**	1.6	1.4	1.7	1.7	0.0	1.6	1.6	1.4



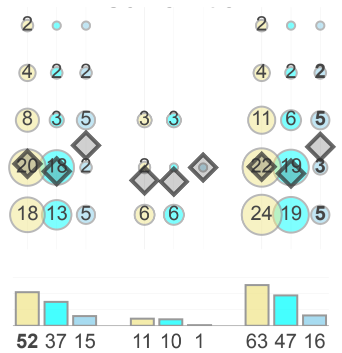
3.00(mean) C2 emp-n-dz

	1st			2nd			both		
Ø	**3.00**	2.9	3.3	3.0	2.9	3.4	3.0	2.9	3.4
σ	**1.34**	1.3	1.3	1.4	1.3	1.6	1.3	1.3	1.4
σ²	**1.80**	1.8	1.8	1.9	1.7	2.5	1.8	1.7	2.0



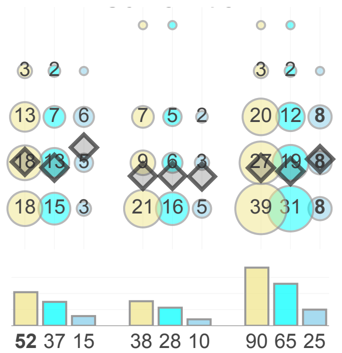
2.08(mean) A1 emp-n-ca10

	1st			2nd			both		
Ø	**2.08**	1.9	2.5	1.7	1.7	2.0	2.0	1.9	2.4
σ	**1.08**	1.0	1.3	0.9	0.9	0.0	1.1	0.9	1.3
σ²	**1.17**	0.9	1.7	0.8	0.9	0.0	1.1	0.9	1.6



2.02(mean) C3 emp-n-fr67

	1st			2nd			both		
Ø	**2.02**	1.9	2.3	1.7	1.7	1.7	1.9	1.8	2.1
σ	**0.92**	0.9	0.9	1.0	1.0	0.8	0.9	1.0	0.9
σ²	**0.84**	0.8	0.8	0.9	1.0	0.7	0.9	0.9	0.8

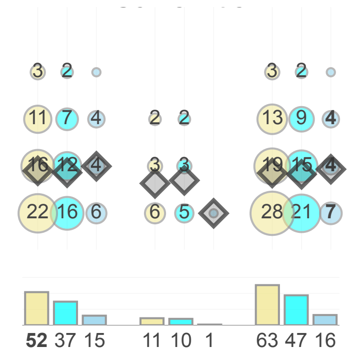


C1 - Expo 2010 Angola Pavilion (Shanghai)

(page 2/2)

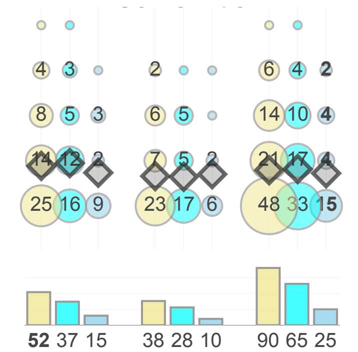
1.90(mean) A2 emp-n-de10

	1st			2nd			both		
Ø	**1.90**	1.9	2.0	1.6	1.7	1.0	1.9	1.8	1.9
σ	**0.93**	0.9	1.0	0.8	0.8	0.0	0.9	0.9	1.0
σ²	**0.87**	0.8	1.0	0.7	0.7	0.0	0.8	0.8	1.0



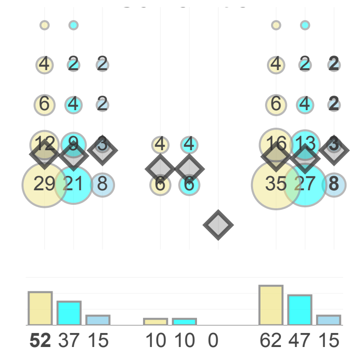
1.88(mean) D1 emp-r-ont

	1st			2nd			both		
Ø	**1.88**	1.9	1.7	1.7	1.6	1.7	1.8	1.8	1.7
σ	**1.06**	1.1	1.0	0.9	0.9	1.1	1.0	1.0	1.0
σ²	**1.12**	1.2	1.1	0.9	0.8	1.1	1.0	1.0	1.0



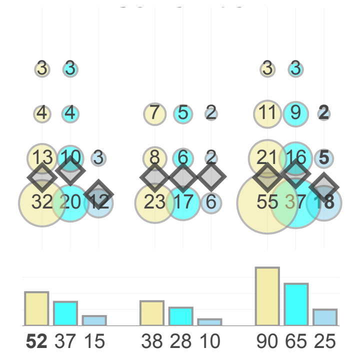
1.77(mean) D3 emp-c-pulp

	1st			2nd			both		
Ø	**1.77**	1.7	1.9	1.4	1.4	0.0	1.7	1.7	1.9
σ	**1.06**	1.0	1.1	0.5	0.5	0.0	1.0	1.0	1.1
σ²	**1.12**	1.1	1.3	0.3	0.3	0.0	1.0	0.9	1.3



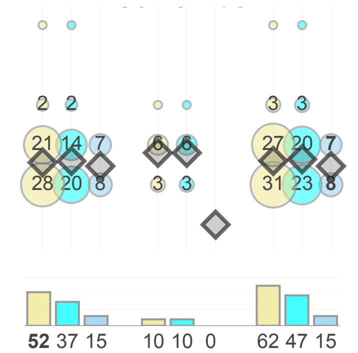
1.58(mean) B1 emp-n-su70

	1st			2nd			both		
Ø	**1.58**	1.7	1.2	1.6	1.6	1.6	1.6	1.7	1.4
σ	**0.87**	1.0	0.4	0.8	0.8	0.8	0.8	0.9	0.6
σ²	**0.76**	0.9	0.2	0.6	0.6	0.7	0.7	0.8	0.4



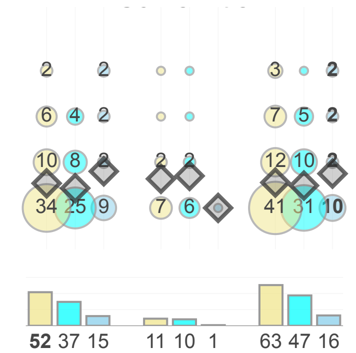
1.56(mean) D2 g-africa

	1st			2nd			both		
Ø	**1.56**	1.6	1.5	1.8	1.8	0.0	1.6	1.6	1.5
σ	**0.75**	0.8	0.5	0.6	0.6	0.0	0.7	0.8	0.5
σ²	**0.57**	0.7	0.3	0.4	0.4	0.0	0.5	0.6	0.3



1.54(mean) C5 emp-n-il

	1st			2nd			both		
Ø	**1.54**	1.4	1.8	1.6	1.7	1.0	1.6	1.5	1.8
σ	**0.85**	0.7	1.1	1.0	1.1	0.0	0.9	0.8	1.1
σ²	**0.72**	0.5	1.3	1.1	1.1	0.0	0.8	0.6	1.3

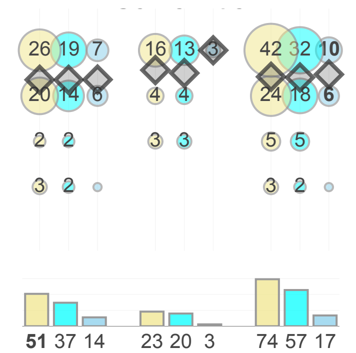


C2 - Expo 2010 Algeria Pavilion (Shanghai)

(page 1/2)

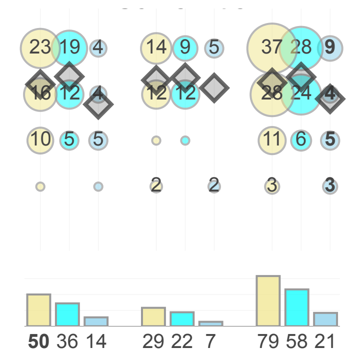
4.35(mean) C7 emp-n-lk

	1st			2nd			both		
Ø	**4.35**	4.4	4.4	4.6	4.5	5.0	4.4	4.4	4.5
σ	**0.82**	0.8	0.8	0.7	0.8	0.0	0.8	0.8	0.8
σ^2	**0.67**	0.7	0.7	0.5	0.6	0.0	0.6	0.6	0.6



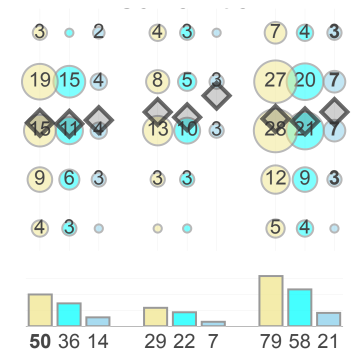
4.22(mean) C6 emp-n-hr

	1st			2nd			both		
Ø	**4.22**	4.4	3.8	4.3	4.4	4.1	4.3	4.4	3.9
σ	**0.84**	0.7	1.0	0.8	0.6	1.5	0.8	0.7	1.1
σ^2	**0.71**	0.5	1.0	0.7	0.3	2.1	0.7	0.5	1.3



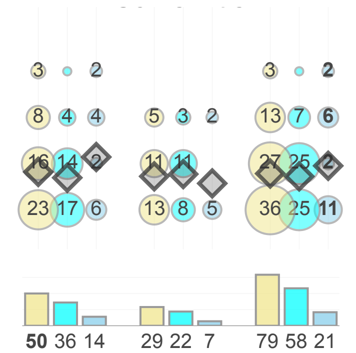
3.16(mean) C4 emp-n-mc

	1st			2nd			both		
Ø	**3.16**	3.1	3.2	3.4	3.3	3.7	3.2	3.2	3.4
σ	**1.06**	1.0	1.2	1.0	1.0	0.8	1.0	1.0	1.1
σ^2	**1.12**	1.0	1.4	1.0	1.1	0.6	1.1	1.0	1.1



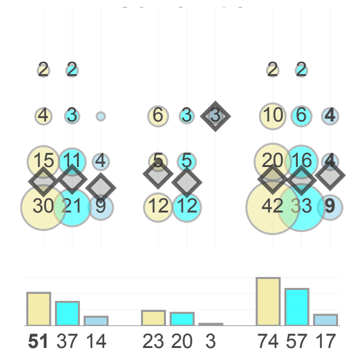
1.82(mean) A2 emp-n-de10

	1st			2nd			both		
Ø	**1.82**	1.7	2.1	1.7	1.8	1.6	1.8	1.7	2.0
σ	**0.92**	0.8	1.2	0.8	0.7	1.0	0.9	0.7	1.1
σ^2	**0.84**	0.6	1.4	0.6	0.5	1.0	0.7	0.6	1.2



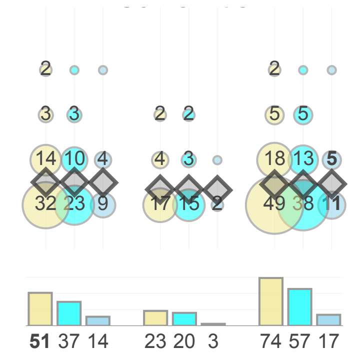
1.57(mean) B3 emp-n-ph

	1st			2nd			both		
Ø	**1.57**	1.6	1.4	1.7	1.6	3.0	1.6	1.6	1.7
σ	**0.81**	0.9	0.6	0.9	0.8	0.0	0.8	0.8	0.8
σ^2	**0.65**	0.7	0.4	0.7	0.6	0.0	0.7	0.7	0.7



1.51(mean) D3 emp-c-pulp

	1st			2nd			both		
Ø	**1.51**	1.5	1.5	1.3	1.4	1.3	1.5	1.5	1.5
σ	**0.78**	0.8	0.9	0.6	0.7	0.6	0.7	0.7	0.8
σ^2	**0.61**	0.6	0.7	0.4	0.5	0.3	0.6	0.5	0.6

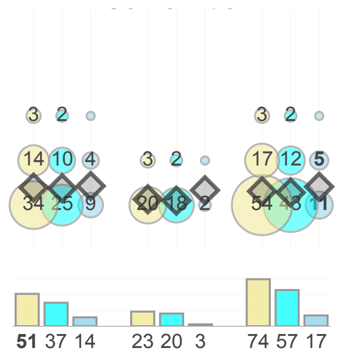


C2 - Expo 2010 Algeria Pavilion (Shanghai)

(page 2/2)

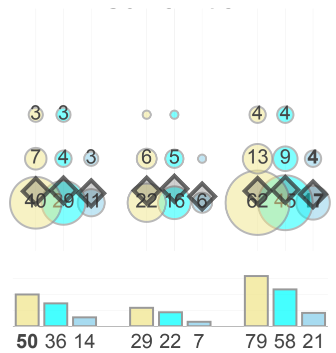
1.39(mean) C5 emp-n-il

	1st			2nd			both		
Ø	**1.39**	1.4	1.4	1.1	1.1	1.3	1.3	1.3	1.4
σ	**0.60**	0.6	0.6	0.3	0.3	0.6	0.5	0.5	0.6
σ^2	**0.36**	0.4	0.4	0.1	0.1	0.3	0.3	0.3	0.4



1.26(mean) D2 g-africa

	1st			2nd			both		
Ø	**1.26**	1.3	1.2	1.3	1.3	1.1	1.3	1.3	1.2
σ	**0.56**	0.6	0.4	0.5	0.6	0.4	0.5	0.6	0.4
σ^2	**0.32**	0.4	0.2	0.3	0.3	0.1	0.3	0.4	0.2

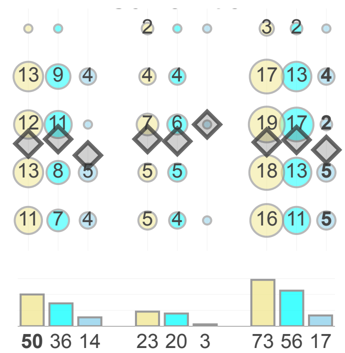


C3 - Expo 1967 France Pavilion (Montreal)

(page 1/2)

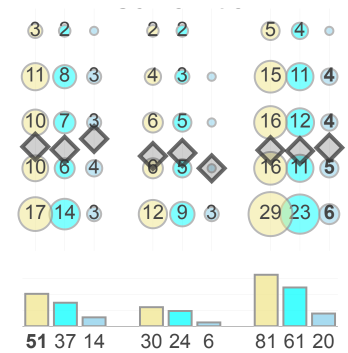
2.60(mean) C5 emp-n-il

		1st			2nd			both	
Ø	**2.60**	2.7	2.4	2.7	2.7	3.0	2.6	2.7	2.5
σ	**1.16**	1.1	1.2	1.3	1.2	2.0	1.2	1.1	1.3
σ²	**1.35**	1.3	1.5	1.6	1.4	4.0	1.4	1.3	1.8



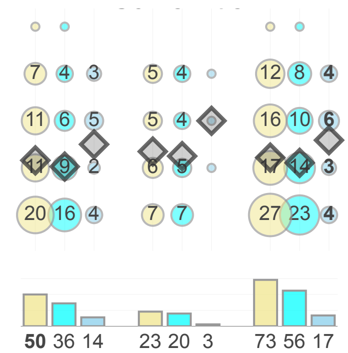
2.47(mean) A2 emp-n-de10

		1st			2nd			both	
Ø	**2.47**	2.4	2.6	2.3	2.3	2.0	2.4	2.4	2.5
σ	**1.32**	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
σ²	**1.73**	1.8	1.6	1.7	1.8	1.6	1.7	1.8	1.6



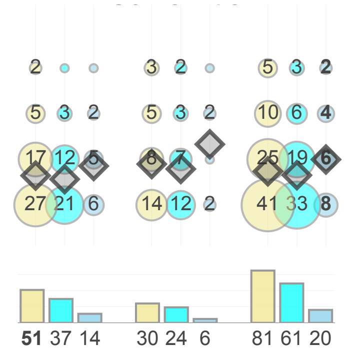
2.16(mean) A3 g-europe

		1st			2nd			both	
Ø	**2.16**	2.0	2.5	2.3	2.3	3.0	2.2	2.1	2.6
σ	**1.17**	1.2	1.2	1.2	1.2	1.0	1.2	1.2	1.1
σ²	**1.36**	1.3	1.3	1.3	1.4	1.0	1.3	1.3	1.3



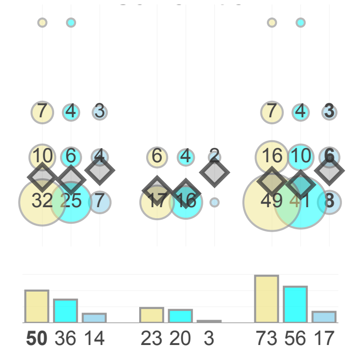
1.65(mean) C4 emp-n-mc

		1st			2nd			both	
Ø	**1.65**	1.6	1.9	1.9	1.8	2.3	1.7	1.7	2.0
σ	**0.82**	0.8	0.9	1.0	1.0	1.2	0.9	0.9	1.0
σ²	**0.67**	0.6	0.9	1.1	1.0	1.5	0.8	0.7	1.1



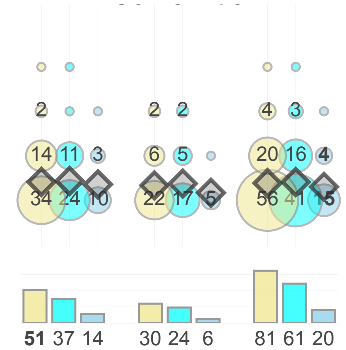
1.56(mean) C6 emp-n-hr

		1st			2nd			both	
Ø	**1.56**	1.5	1.7	1.3	1.2	1.7	1.5	1.4	1.7
σ	**0.88**	0.9	0.8	0.4	0.4	0.6	0.8	0.8	0.8
σ²	**0.78**	0.8	0.7	0.2	0.2	0.3	0.6	0.6	0.6



1.41(mean) C7 emp-n-lk

		1st			2nd			both	
Ø	**1.41**	1.4	1.4	1.3	1.4	1.2	1.4	1.4	1.3
σ	**0.67**	0.7	0.6	0.6	0.6	0.4	0.6	0.7	0.6
σ²	**0.45**	0.5	0.4	0.4	0.4	0.2	0.4	0.4	0.3

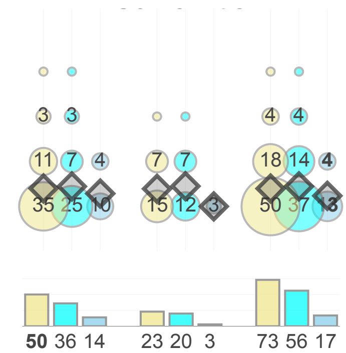


C3 - Expo 1967 France Pavilion (Montreal)

(page 2/2)

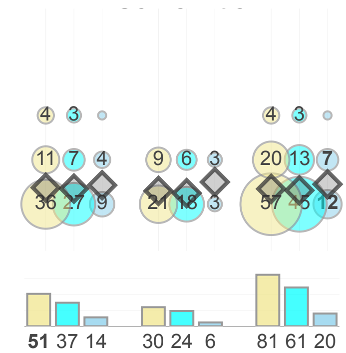
1.40(mean) D3 emp-c-pulp

		1st			2nd			both		
Ø	**1.40**	1.4	1.3	1.4	1.5	1.0	1.4	1.4	1.2	
σ	**0.70**	0.8	0.5	0.6	0.6	0.0	0.7	0.7	0.4	
σ²	**0.49**	0.6	0.2	0.3	0.4	0.0	0.4	0.5	0.2	



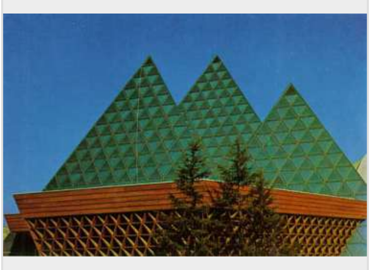
1.37(mean) C2 emp-n-dz

		1st			2nd			both		
Ø	**1.37**	1.4	1.4	1.3	1.3	1.5	1.3	1.3	1.5	
σ	**0.63**	0.6	0.6	0.5	0.4	0.5	0.6	0.6	0.6	
σ²	**0.40**	0.4	0.4	0.2	0.2	0.3	0.3	0.3	0.4	



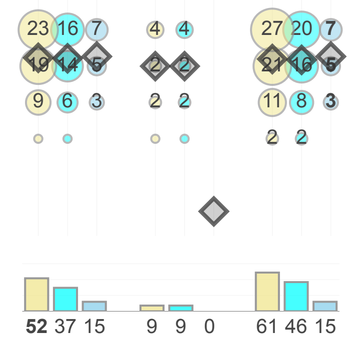
D1 - Expo 1967 Ontario Region Pavilion (Montreal)

(page 1/2)



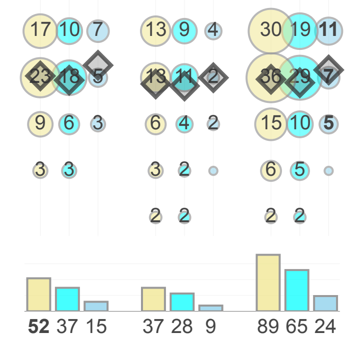
4.23(mean) D7 emp-n-bg

	1st			2nd			both		
Ø	**4.23**	4.2	4.3	4.0	4.0	0.0	4.2	4.2	4.3
σ	**0.81**	0.8	0.8	1.1	1.1	0.0	0.9	0.9	0.8
σ^2	**0.65**	0.7	0.6	1.3	1.3	0.0	0.7	0.8	0.6



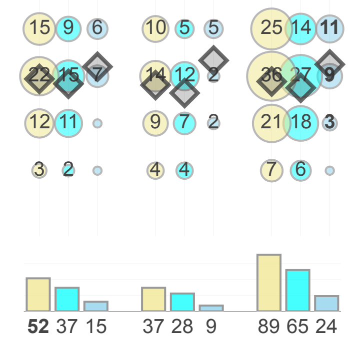
4.04(mean) D3 emp-c-pulp

	1st			2nd			both		
Ø	**4.04**	3.9	4.3	3.9	3.8	4.0	4.0	3.9	4.2
σ	**0.86**	0.9	0.8	1.2	1.2	1.1	1.0	1.0	0.9
σ^2	**0.74**	0.8	0.6	1.3	1.4	1.3	1.0	1.0	0.8



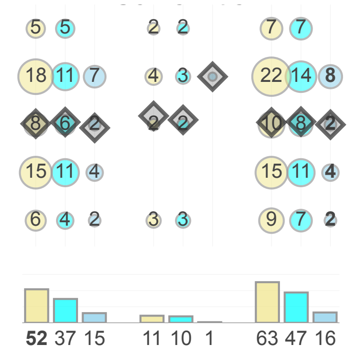
3.94(mean) D2 g-africa

	1st			2nd			both		
Ø	**3.94**	3.8	4.2	3.8	3.6	4.3	3.9	3.8	4.3
σ	**0.87**	0.9	0.9	1.0	1.0	0.9	0.9	0.9	0.8
σ^2	**0.76**	0.8	0.7	0.9	0.9	0.8	0.8	0.8	0.7



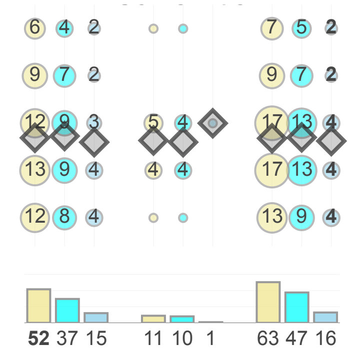
3.02(mean) D5 t-cases

	1st			2nd			both		
Ø	**3.02**	3.1	2.9	3.2	3.1	4.0	3.0	3.1	3.0
σ	**1.23**	1.3	1.2	1.5	1.6	0.0	1.3	1.3	1.2
σ^2	**1.51**	1.6	1.4	2.4	2.5	0.0	1.6	1.8	1.3



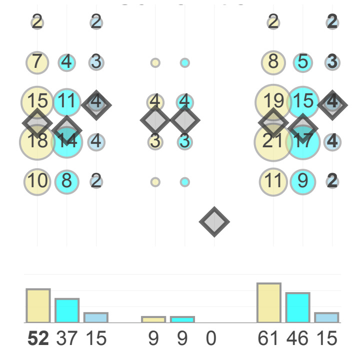
2.69(mean) B1 emp-n-su70

	1st			2nd			both		
Ø	**2.69**	2.7	2.6	2.6	2.6	3.0	2.7	2.7	2.6
σ	**1.32**	1.3	1.4	1.0	1.1	0.0	1.3	1.2	1.4
σ^2	**1.75**	1.7	2.0	1.1	1.2	0.0	1.6	1.6	1.9



2.48(mean) A2 emp-n-de10

	1st			2nd			both		
Ø	**2.48**	2.3	2.9	2.6	2.6	0.0	2.5	2.3	2.9
σ	**1.08**	0.9	1.3	0.9	0.9	0.0	1.0	0.9	1.3
σ^2	**1.16**	0.9	1.6	0.8	0.8	0.0	1.1	0.9	1.6

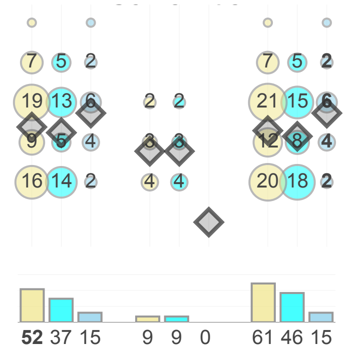


D1 - Expo 1967 Ontario Region Pavilion (Montreal)

(page 2/2)

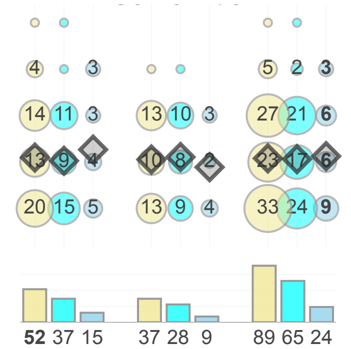
2.38(mean) A3 g-europe

	1st			2nd			both		
Ø	**2.38**	2.2	2.7	1.8	1.8	0.0	2.3	2.2	2.7
σ	**1.12**	1.1	1.1	0.8	0.8	0.0	1.1	1.1	1.1
σ²	**1.26**	1.2	1.2	0.7	0.7	0.0	1.2	1.2	1.2



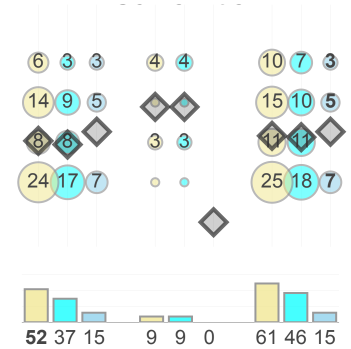
2.10(mean) A1 emp-n-ca10

	1st			2nd			both		
Ø	**2.10**	2.0	2.3	2.1	2.1	1.9	2.1	2.1	2.1
σ	**1.07**	1.0	1.2	0.9	0.9	0.9	1.0	1.0	1.1
σ²	**1.15**	1.1	1.4	0.8	0.8	0.9	1.0	1.0	1.2



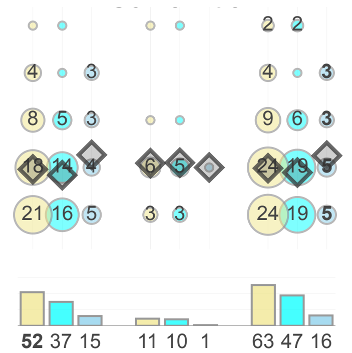
2.04(mean) D6 emp-n-nl10

	1st			2nd			both		
Ø	**2.04**	1.9	2.3	2.9	2.9	0.0	2.2	2.1	2.3
σ	**1.10**	1.0	1.3	1.2	1.2	0.0	1.1	1.1	1.3
σ²	**1.21**	1.1	1.6	1.4	1.4	0.0	1.3	1.2	1.6



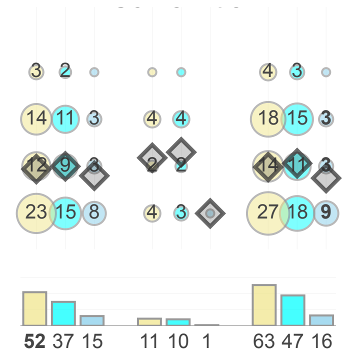
1.96(mean) B2 emp-n-uk

	1st			2nd			both		
Ø	**1.96**	1.8	2.3	2.1	2.1	2.0	2.0	1.9	2.3
σ	**1.03**	1.0	1.2	1.1	1.2	0.0	1.0	1.0	1.1
σ²	**1.06**	0.9	1.4	1.3	1.4	0.0	1.1	1.0	1.3



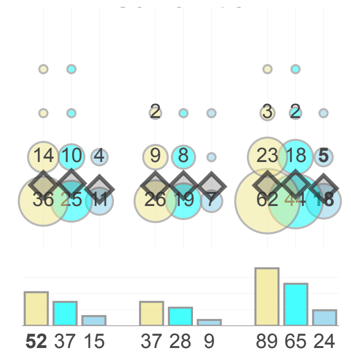
1.94(mean) D4 c-wanke

	1st			2nd			both		
Ø	**1.94**	2.0	1.8	2.2	2.3	1.0	2.0	2.1	1.8
σ	**0.98**	1.0	1.0	1.1	1.1	0.0	1.0	1.0	1.0
σ²	**0.96**	0.9	1.0	1.2	1.1	0.0	1.0	1.0	1.0



1.37(mean) C1 emp-n-ao

	1st			2nd			both		
Ø	**1.37**	1.4	1.3	1.4	1.4	1.3	1.4	1.4	1.3
σ	**0.63**	0.7	0.5	0.6	0.6	0.7	0.6	0.6	0.6
σ²	**0.39**	0.5	0.2	0.3	0.3	0.5	0.4	0.4	0.3

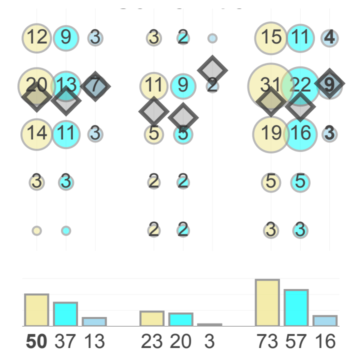


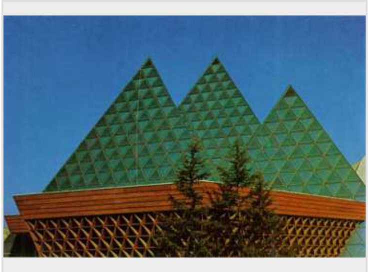
D2 - Expo 1967 Africa Group Pavilion (Montreal)

(page 1/2)

3.78(mean) D5 t-cases

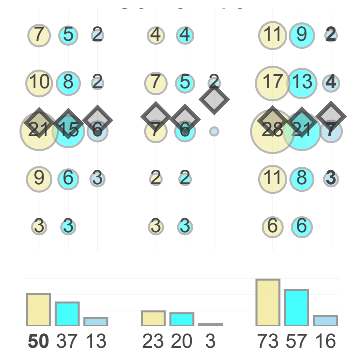
	1st			2nd			both		
Ø	**3.78**	3.7	4.0	3.5	3.4	4.3	3.7	3.6	4.1
σ	**0.95**	1.0	0.7	1.1	1.1	0.6	1.0	1.1	0.7
$σ^2$	**0.91**	1.0	0.5	1.3	1.3	0.3	1.0	1.1	0.5





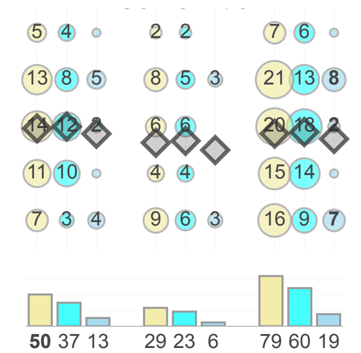
3.18(mean) D7 emp-n-bg

	1st			2nd			both		
Ø	**3.18**	3.2	3.2	3.3	3.3	3.7	3.2	3.2	3.3
σ	**1.08**	1.1	1.0	1.3	1.3	0.6	1.1	1.2	0.9
$σ^2$	**1.17**	1.3	1.0	1.6	1.8	0.3	1.3	1.4	0.9



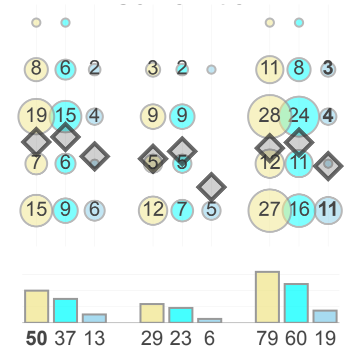
2.96(mean) D6 emp-n-nl10

	1st			2nd			both		
Ø	**2.96**	3.0	2.8	2.7	2.7	2.5	2.8	2.9	2.7
σ	**1.21**	1.1	1.5	1.4	1.3	1.6	1.3	1.2	1.5
$σ^2$	**1.47**	1.3	2.1	1.9	1.8	2.7	1.6	1.5	2.2



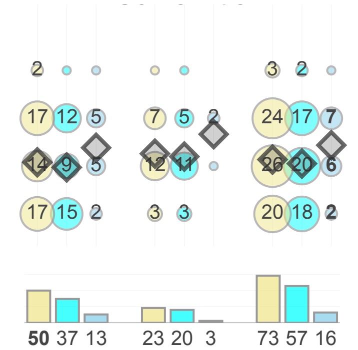
2.46(mean) D4 c-wanke

	1st			2nd			both		
Ø	**2.46**	2.6	2.2	2.1	2.3	1.5	2.3	2.5	1.9
σ	**1.15**	1.1	1.2	1.1	1.0	1.2	1.1	1.1	1.2
$σ^2$	**1.31**	1.3	1.5	1.2	1.0	1.5	1.3	1.2	1.5



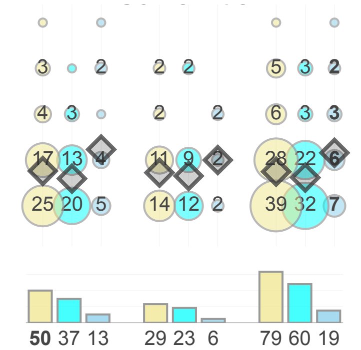
2.08(mean) A3 g-europe

	1st			2nd			both		
Ø	**2.08**	2.0	2.4	2.3	2.2	2.7	2.1	2.1	2.4
σ	**0.92**	0.9	0.9	0.8	0.8	0.6	0.9	0.9	0.8
$σ^2$	**0.85**	0.9	0.8	0.6	0.6	0.3	0.8	0.8	0.7



1.76(mean) B2 emp-n-uk

	1st			2nd			both		
Ø	**1.76**	1.6	2.2	1.7	1.7	2.0	1.7	1.6	2.2
σ	**0.98**	0.8	1.4	0.9	0.9	0.9	0.9	0.8	1.2
$σ^2$	**0.96**	0.6	1.9	0.8	0.8	0.8	0.9	0.6	1.5

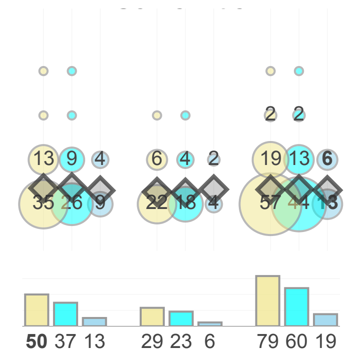


D2 - Expo 1967 Africa Group Pavilion (Montreal)

(page 2/2)

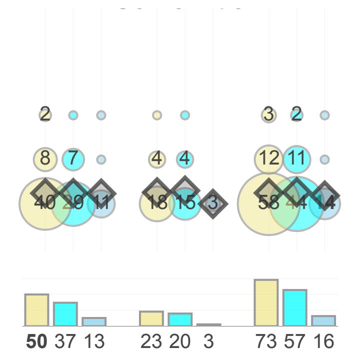
1.36(mean) C4 emp-n-mc

	1st			2nd			both		
∅	**1.36**	1.4	1.3	1.3	1.3	1.3	1.3	1.3	1.3
σ	**0.63**	0.7	0.5	0.5	0.5	0.5	0.6	0.6	0.5
σ^2	**0.40**	0.5	0.2	0.3	0.3	0.3	0.4	0.4	0.2



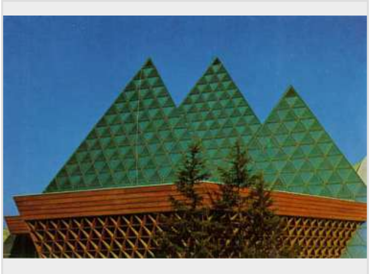
1.24(mean) C3 emp-n-fr67

	1st			2nd			both		
∅	**1.24**	1.2	1.2	1.3	1.3	1.0	1.2	1.3	1.2
σ	**0.52**	0.5	0.6	0.5	0.6	0.0	0.5	0.5	0.5
σ^2	**0.27**	0.2	0.4	0.3	0.3	0.0	0.3	0.3	0.3



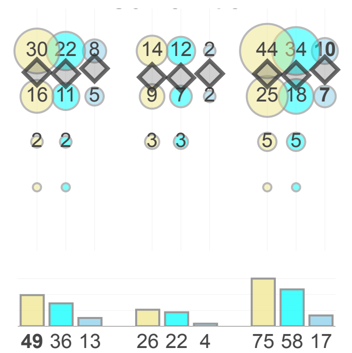
D3 - Expo 1967 Pulp and Paper Corporate Pav. (Montreal)

(page 1/2)



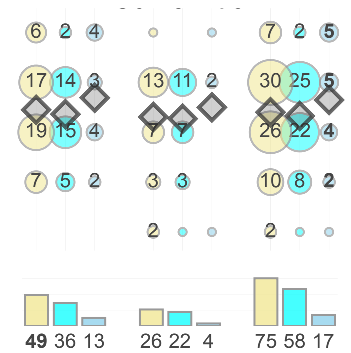
4.53(mean) D7 emp-n-bg

	1st			2nd			both		
Ø	**4.53**	4.5	4.6	4.4	4.4	4.5	4.5	4.5	4.6
σ	**0.68**	0.7	0.5	0.7	0.7	0.6	0.7	0.7	0.5
σ²	**0.46**	0.5	0.3	0.5	0.5	0.3	0.5	0.5	0.3



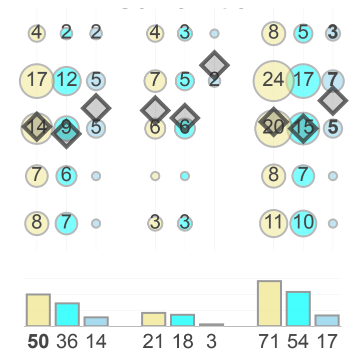
3.45(mean) D2 g-africa

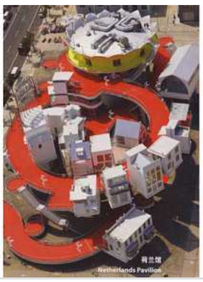
	1st			2nd			both		
Ø	**3.45**	3.4	3.7	3.3	3.3	3.5	3.4	3.3	3.6
σ	**0.89**	0.8	1.1	1.0	0.9	1.7	0.9	0.8	1.2
σ²	**0.79**	0.6	1.2	1.0	0.8	3.0	0.9	0.7	1.5



3.04(mean) D5 t-cases

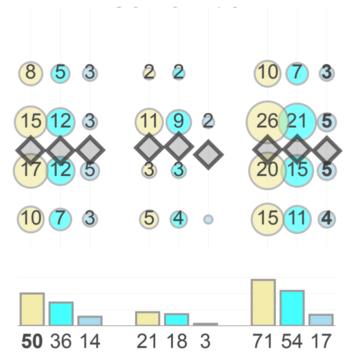
	1st			2nd			both		
Ø	**3.04**	2.9	3.4	3.4	3.2	4.3	3.1	3.0	3.6
σ	**1.21**	1.2	1.1	1.3	1.3	0.6	1.2	1.3	1.1
σ²	**1.47**	1.5	1.2	1.6	1.7	0.3	1.5	1.6	1.1





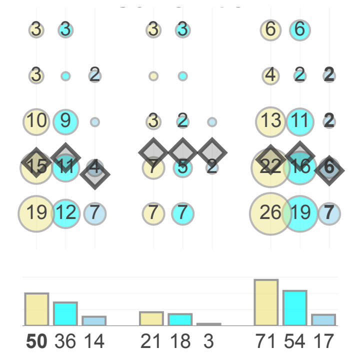
2.42(mean) D6 emp-n-nl10

	1st			2nd			both		
Ø	**2.42**	2.4	2.4	2.5	2.5	2.3	2.4	2.4	2.4
σ	**0.99**	1.0	1.1	1.0	1.0	1.2	1.0	1.0	1.1
σ²	**0.98**	0.9	1.2	1.0	1.0	1.3	1.0	0.9	1.1



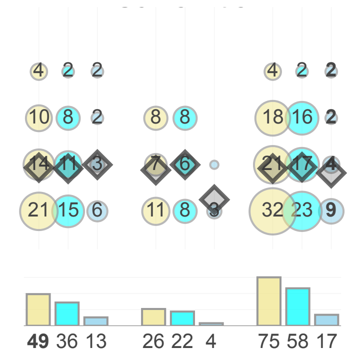
2.12(mean) B3 emp-n-ph

	1st			2nd			both		
Ø	**2.12**	2.2	1.9	2.3	2.3	2.3	2.2	2.3	1.9
σ	**1.17**	1.2	1.1	1.4	1.5	0.6	1.2	1.3	1.0
σ²	**1.37**	1.4	1.2	1.9	2.2	0.3	1.5	1.7	1.1



1.94(mean) D4 c-wanke

	1st			2nd			both		
Ø	**1.94**	1.9	2.0	1.9	2.0	1.3	1.9	1.9	1.8
σ	**0.99**	0.9	1.2	0.9	0.9	0.5	0.9	0.9	1.1
σ²	**0.98**	0.9	1.3	0.7	0.8	0.3	0.9	0.8	1.2

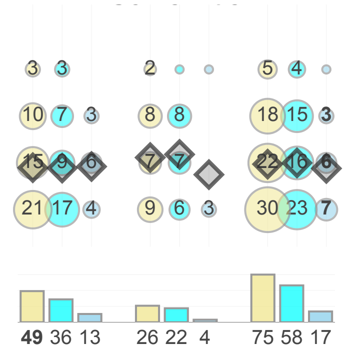


D3 - Expo 1967 Pulp and Paper Corporate Pav. (Montreal)

(page 2/2)

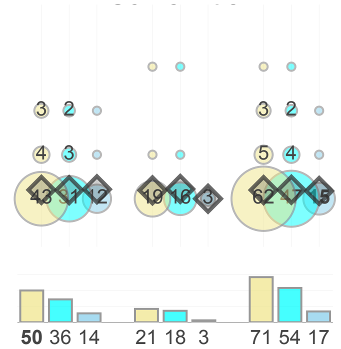
1.90(mean) B2 emp-n-uk

	1st			2nd			both		
Ø	**1.90**	1.9	1.9	2.1	2.2	1.8	2.0	2.0	1.9
σ	**0.94**	1.0	0.8	1.0	0.9	1.5	1.0	1.0	0.9
$σ^2$	**0.89**	1.0	0.6	1.0	0.8	2.3	0.9	0.9	0.9

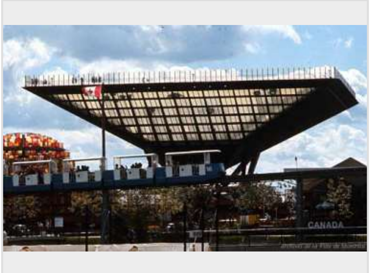


1.20(mean) C5 emp-n-il

	1st			2nd			both		
Ø	**1.20**	1.2	1.2	1.2	1.2	1.0	1.2	1.2	1.2
σ	**0.53**	0.5	0.6	0.7	0.7	0.0	0.6	0.6	0.5
$σ^2$	**0.29**	0.3	0.3	0.5	0.5	0.0	0.3	0.4	0.3



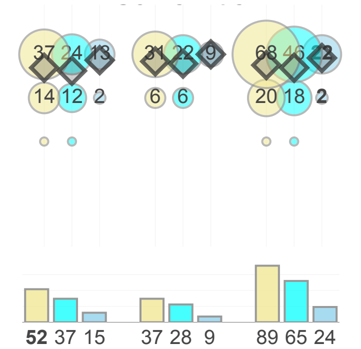
E1 - Expo 1967 Canada Host-Pavilion (Montreal)

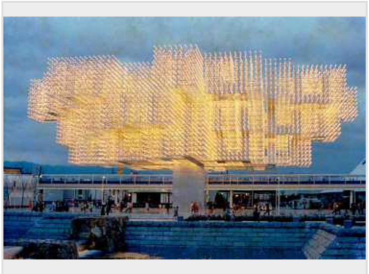


(page 1/2)

4.69(mean) E2 host-cn

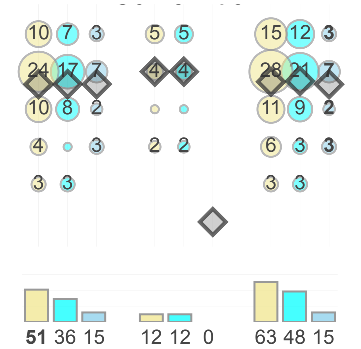
	1st			2nd			both		
Ø	**4.69**	4.6	4.9	4.8	4.8	5.0	4.8	4.7	4.9
σ	**0.51**	0.5	0.4	0.4	0.4	0.0	0.5	0.5	0.3
σ²	**0.26**	0.3	0.1	0.1	0.2	0.0	0.2	0.2	0.1





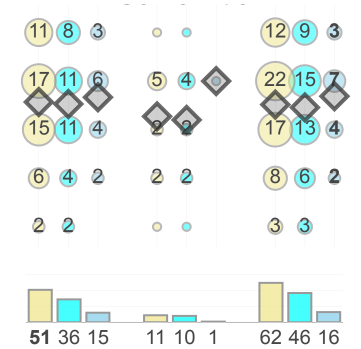
3.67(mean) E5 emp-n-ch

	1st			2nd			both		
Ø	**3.67**	3.7	3.7	4.0	4.0	0.0	3.7	3.8	3.7
σ	**1.07**	1.1	1.0	1.1	1.1	0.0	1.1	1.1	1.0
σ²	**1.15**	1.2	1.1	1.3	1.3	0.0	1.2	1.2	1.1



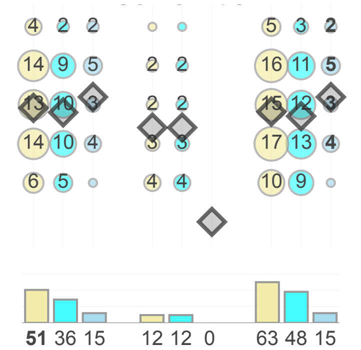
3.57(mean) E6 r-quebec

	1st			2nd			both		
Ø	**3.57**	3.5	3.7	3.3	3.2	4.0	3.5	3.5	3.7
σ	**1.08**	1.1	1.0	1.2	1.2	0.0	1.1	1.1	0.9
σ²	**1.17**	1.3	1.0	1.4	1.5	0.0	1.2	1.3	0.9



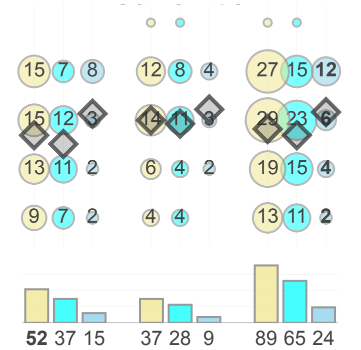
2.92(mean) E4 emp-n-sa

	1st			2nd			both		
Ø	**2.92**	2.8	3.2	2.4	2.4	0.0	2.8	2.7	3.2
σ	**1.16**	1.1	1.2	1.4	1.4	0.0	1.2	1.2	1.2
σ²	**1.35**	1.3	1.5	1.9	1.9	0.0	1.5	1.4	1.5



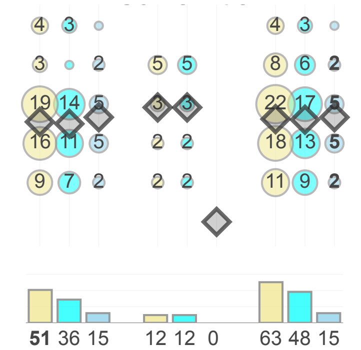
2.69(mean) E3 c-chemical

	1st			2nd			both		
Ø	**2.69**	2.5	3.1	3.0	2.9	3.2	2.8	2.7	3.2
σ	**1.08**	1.0	1.1	1.0	1.1	0.8	1.1	1.1	1.0
σ²	**1.16**	1.0	1.3	1.1	1.2	0.7	1.1	1.1	1.0

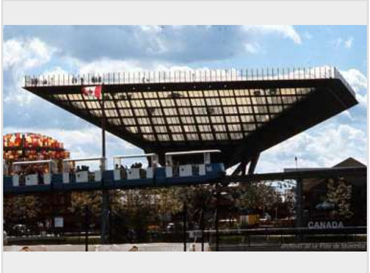


2.55(mean) G1 emp-n-su67

	1st			2nd			both		
Ø	**2.55**	2.5	2.7	2.9	2.9	0.0	2.6	2.6	2.7
σ	**1.10**	1.1	1.1	1.2	1.2	0.0	1.1	1.1	1.1
σ²	**1.21**	1.2	1.2	1.4	1.4	0.0	1.2	1.3	1.2



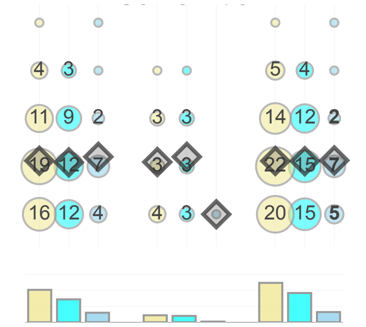
E1 - Expo 1967 Canada Host-Pavilion (Montreal)



(page 2/2)

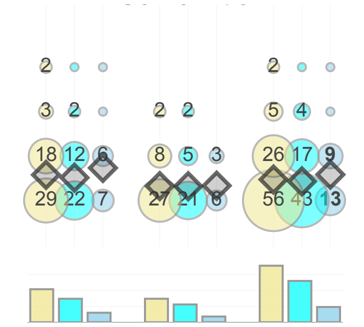
2.12(mean) E7 emp-n-kr

	1st			2nd			both		
Ø	**2.12**	2.1	2.2	2.1	2.2	1.0	2.1	2.1	2.1
σ	**1.01**	1.0	1.1	1.0	1.0	0.0	1.0	1.0	1.1
σ²	**1.03**	0.9	1.3	1.1	1.1	0.0	1.0	0.9	1.3



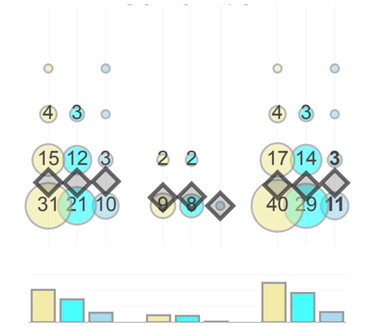
1.58(mean) H1 emp-n-cl

	1st			2nd			both		
Ø	**1.58**	1.5	1.7	1.3	1.3	1.3	1.5	1.4	1.6
σ	**0.78**	0.7	0.9	0.6	0.6	0.5	0.7	0.7	0.8
σ²	**0.60**	0.5	0.8	0.3	0.4	0.3	0.5	0.5	0.6



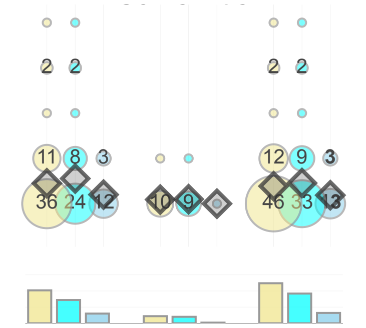
1.51(mean) F3 emp-n-jp00

	1st			2nd			both		
Ø	**1.51**	1.5	1.5	1.2	1.2	1.0	1.5	1.4	1.5
σ	**0.73**	0.7	0.9	0.4	0.4	0.0	0.7	0.6	0.9
σ²	**0.53**	0.4	0.8	0.2	0.2	0.0	0.5	0.4	0.8



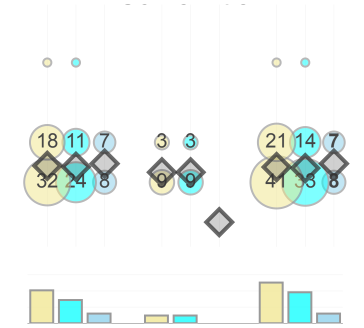
1.45(mean) F2 emp-n-jp10

	1st			2nd			both		
Ø	**1.45**	1.6	1.2	1.1	1.1	1.0	1.4	1.5	1.2
σ	**0.88**	1.0	0.4	0.3	0.3	0.0	0.8	0.9	0.4
σ²	**0.77**	1.0	0.2	0.1	0.1	0.0	0.7	0.8	0.2



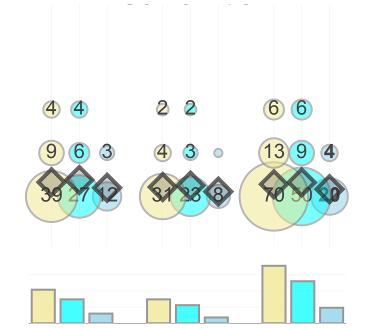
1.41(mean) G2 c-hyundai

	1st			2nd			both		
Ø	**1.41**	1.4	1.5	1.3	1.3	0.0	1.4	1.4	1.5
σ	**0.61**	0.6	0.5	0.5	0.5	0.0	0.6	0.6	0.5
σ²	**0.37**	0.4	0.3	0.2	0.2	0.0	0.3	0.4	0.3



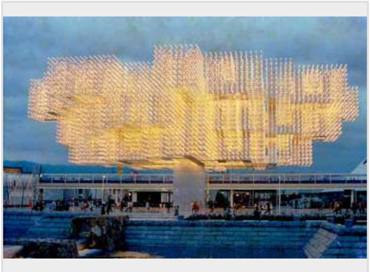
1.33(mean) F1 emp-c-fuji

	1st			2nd			both		
Ø	**1.33**	1.4	1.2	1.2	1.3	1.1	1.3	1.3	1.2
σ	**0.62**	0.7	0.4	0.5	0.6	0.3	0.6	0.6	0.4
σ²	**0.38**	0.5	0.2	0.3	0.3	0.1	0.3	0.4	0.1



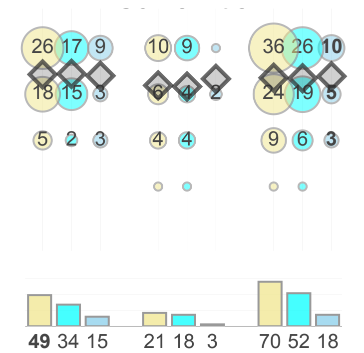
E2 - Expo 2010 China Host Pavilion (Shanghai)

(page 1/2)



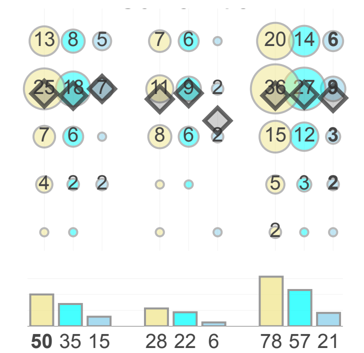
4.43(mean) E5 emp-n-ch

	1st			2nd			both		
Ø	**4.43**	4.4	4.4	4.2	4.2	4.3	4.4	4.3	4.4
σ	**0.68**	0.6	0.8	0.9	1.0	0.6	0.8	0.8	0.8
σ²	**0.46**	0.4	0.7	0.9	1.0	0.3	0.6	0.6	0.6



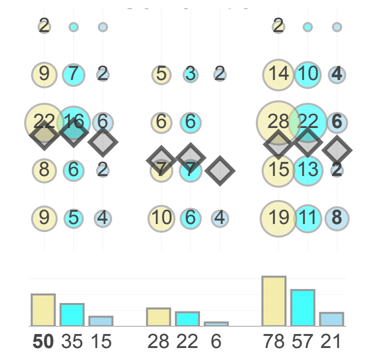
3.90(mean) E6 r-quebec

	1st			2nd			both		
Ø	**3.90**	3.9	4.0	3.8	3.9	3.3	3.9	3.9	3.8
σ	**0.95**	0.9	1.0	1.0	0.9	1.4	1.0	0.9	1.1
σ²	**0.91**	0.9	1.0	1.0	0.8	1.9	0.9	0.8	1.3



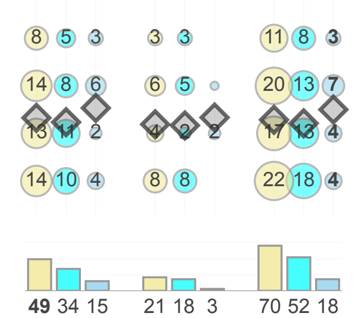
2.74(mean) E4 emp-n-sa

	1st			2nd			both		
Ø	**2.74**	2.8	2.6	2.2	2.3	2.0	2.6	2.6	2.4
σ	**1.08**	1.0	1.2	1.1	1.0	1.5	1.1	1.0	1.3
σ²	**1.18**	1.0	1.5	1.3	1.1	2.4	1.3	1.1	1.8



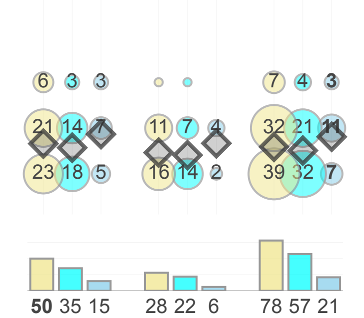
2.33(mean) E7 emp-n-kr

	1st			2nd			both		
Ø	**2.33**	2.2	2.5	2.2	2.2	2.3	2.3	2.2	2.5
σ	**1.07**	1.0	1.1	1.1	1.2	0.6	1.1	1.1	1.0
σ²	**1.14**	1.1	1.3	1.3	1.4	0.3	1.2	1.2	1.1



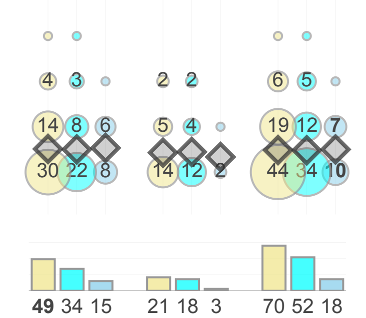
1.66(mean) H2 emp-c-info

	1st			2nd			both		
Ø	**1.66**	1.6	1.9	1.5	1.4	1.7	1.6	1.5	1.8
σ	**0.69**	0.7	0.7	0.6	0.6	0.5	0.7	0.6	0.7
σ²	**0.47**	0.4	0.6	0.3	0.3	0.3	0.4	0.4	0.5



1.51(mean) H3 emp-n-au10

	1st			2nd			both		
Ø	**1.51**	1.5	1.5	1.4	1.4	1.3	1.5	1.5	1.5
σ	**0.74**	0.8	0.6	0.7	0.7	0.6	0.7	0.8	0.6
σ²	**0.55**	0.6	0.4	0.5	0.5	0.3	0.5	0.6	0.4

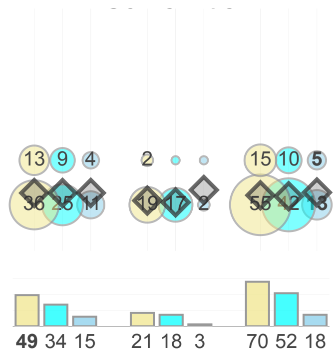


E2 - Expo 2010 China Host Pavilion (Shanghai)

(page 2/2)

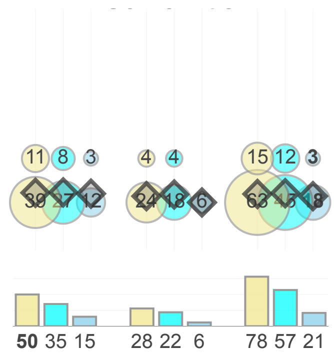
1.27(mean) F3 emp-n-jp00

	1st			2nd			both		
Ø	**1.27**	1.3	1.3	1.1	1.1	1.3	1.2	1.2	1.3
σ	**0.45**	0.4	0.5	0.3	0.2	0.6	0.4	0.4	0.5
σ^2	**0.20**	0.2	0.2	0.1	0.1	0.3	0.2	0.2	0.2



1.22(mean) F2 emp-n-jp10

	1st			2nd			both		
Ø	**1.22**	1.2	1.2	1.1	1.2	1.0	1.2	1.2	1.1
σ	**0.42**	0.4	0.4	0.4	0.4	0.0	0.4	0.4	0.4
σ^2	**0.18**	0.2	0.2	0.1	0.2	0.0	0.2	0.2	0.1

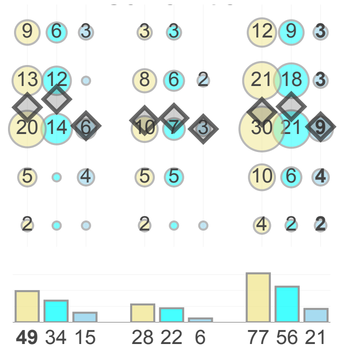


E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)

(page 1/2)

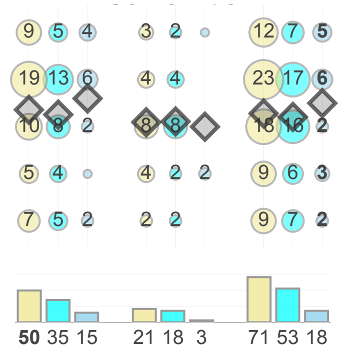
3.45(mean) E4 emp-n-sa

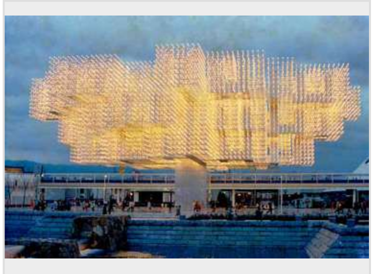
	1st			2nd			both		
Ø	**3.45**	3.6	3.1	3.2	3.2	3.0	3.4	3.5	3.0
σ	**1.04**	0.9	1.2	1.1	1.1	1.1	1.1	1.0	1.2
σ²	**1.09**	0.8	1.5	1.2	1.2	1.2	1.1	1.0	1.3



3.36(mean) E6 r-quebec

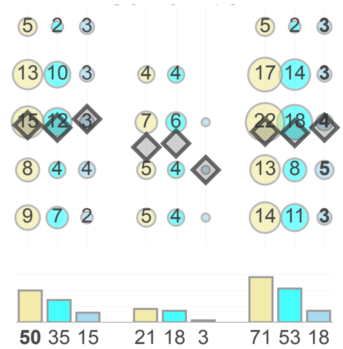
	1st			2nd			both		
Ø	**3.36**	3.3	3.6	3.1	3.1	3.0	3.3	3.2	3.5
σ	**1.29**	1.3	1.4	1.2	1.1	1.7	1.3	1.2	1.4
σ²	**1.66**	1.6	1.8	1.4	1.3	3.0	1.6	1.5	1.9





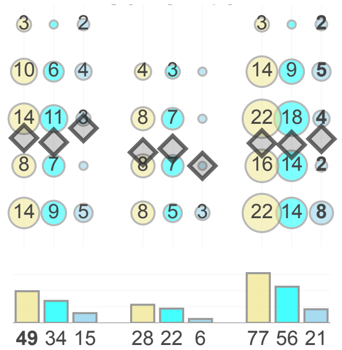
2.94(mean) E5 emp-n-ch

	1st			2nd			both		
Ø	**2.94**	2.9	3.1	2.5	2.6	2.0	2.8	2.8	2.9
σ	**1.25**	1.2	1.4	1.1	1.1	1.0	1.2	1.2	1.4
σ²	**1.57**	1.5	1.9	1.2	1.2	1.0	1.5	1.4	1.9



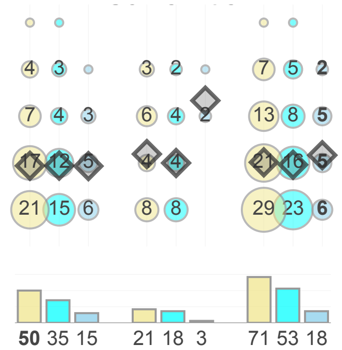
2.59(mean) E2 host-cn

	1st			2nd			both		
Ø	**2.59**	2.5	2.8	2.3	2.4	2.0	2.5	2.4	2.6
σ	**1.27**	1.2	1.5	1.0	1.0	1.3	1.2	1.1	1.5
σ²	**1.62**	1.3	2.3	1.1	1.0	1.6	1.4	1.2	2.2



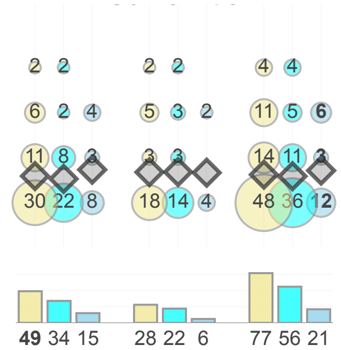
1.94(mean) H3 emp-n-au10

	1st			2nd			both		
Ø	**1.94**	1.9	1.9	2.2	2.0	3.3	2.0	2.0	2.2
σ	**1.04**	1.1	1.0	1.1	1.1	0.6	1.1	1.1	1.0
σ²	**1.08**	1.2	0.9	1.3	1.2	0.3	1.1	1.2	1.1



1.59(mean) E7 emp-n-kr

	1st			2nd			both		
Ø	**1.59**	1.5	1.7	1.7	1.7	1.7	1.6	1.6	1.7
σ	**0.86**	0.9	0.9	1.0	1.0	1.0	0.9	0.9	0.9
σ²	**0.75**	0.7	0.8	1.0	1.1	1.1	0.8	0.9	0.8

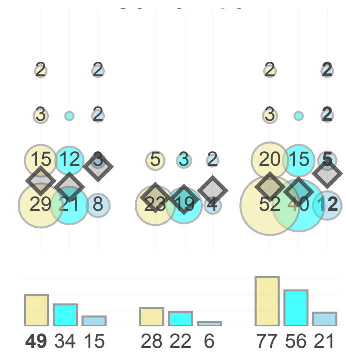


E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)

(page 2/2)

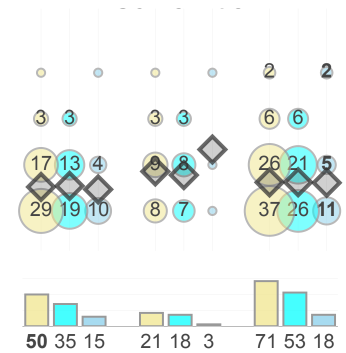
1.55(mean) G2 c-hyundai

	1st			2nd			both		
Ø	**1.55**	1.4	1.9	1.2	1.1	1.3	1.4	1.3	1.7
σ	**0.79**	0.6	1.1	0.4	0.4	0.5	0.7	0.5	1.0
σ²	**0.63**	0.3	1.3	0.2	0.1	0.3	0.5	0.3	1.0



1.52(mean) F3 emp-n-jp00

	1st			2nd			both		
Ø	**1.52**	1.5	1.5	1.9	1.8	2.3	1.6	1.6	1.6
σ	**0.71**	0.7	0.8	0.9	0.7	1.5	0.8	0.7	1.0
σ²	**0.50**	0.4	0.7	0.7	0.5	2.3	0.6	0.5	1.0

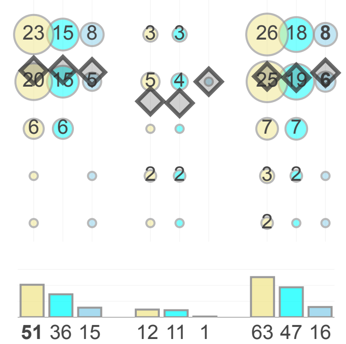


F1 - Expo 1970 Fuji Corporate Pavilion (Osaka)

(page 1/2)

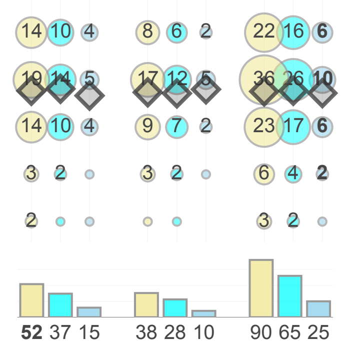
4.24(mean) F5 c-aviation

	1st			2nd			both		
∅	**4.24**	4.3	4.2	3.6	3.5	4.0	4.1	4.1	4.2
σ	**0.89**	0.7	1.2	1.3	1.4	0.0	1.0	1.0	1.2
$σ^2$	**0.78**	0.5	1.5	1.7	1.9	0.0	1.0	0.9	1.4



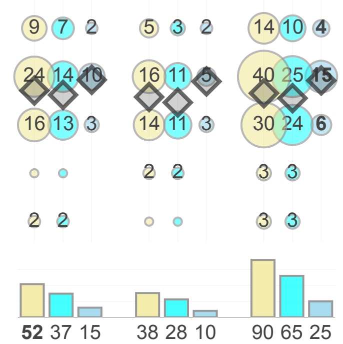
3.77(mean) F3 emp-n-jp00

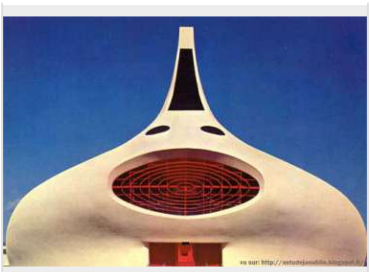
	1st			2nd			both		
∅	**3.77**	3.8	3.7	3.7	3.7	3.8	3.8	3.8	3.7
σ	**1.04**	1.0	1.2	1.0	1.0	0.9	1.0	1.0	1.1
$σ^2$	**1.08**	1.0	1.4	1.0	1.0	0.8	1.0	1.0	1.1



3.71(mean) F2 emp-n-jp10

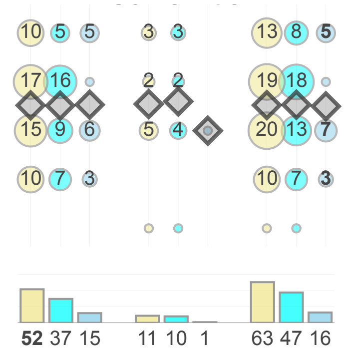
	1st			2nd			both		
∅	**3.71**	3.6	3.9	3.6	3.5	3.9	3.7	3.6	3.9
σ	**0.91**	1.0	0.6	0.9	0.9	0.7	0.9	1.0	0.6
$σ^2$	**0.84**	1.0	0.4	0.8	0.9	0.5	0.8	0.9	0.4





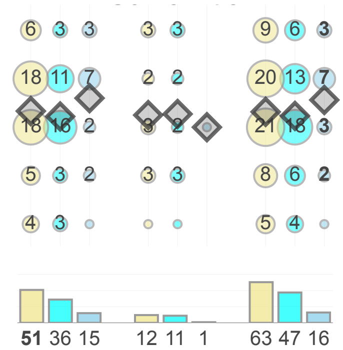
3.52(mean) F7 emp-c-gas

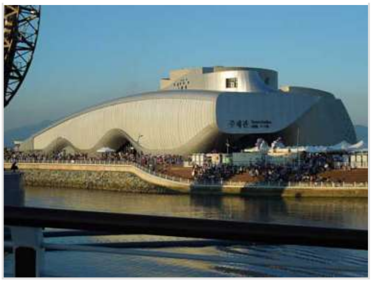
	1st			2nd			both		
∅	**3.52**	3.5	3.5	3.5	3.6	3.0	3.5	3.5	3.5
σ	**1.02**	1.0	1.2	1.2	1.3	0.0	1.0	1.0	1.2
$σ^2$	**1.04**	0.9	1.4	1.5	1.6	0.0	1.1	1.0	1.3



3.33(mean) F4 emp-t-hope

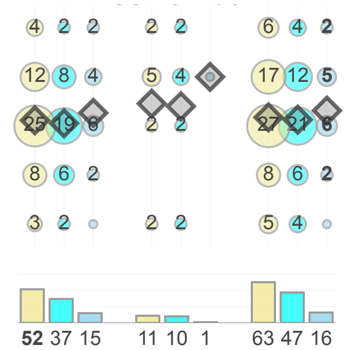
	1st			2nd			both		
∅	**3.33**	3.2	3.6	3.3	3.3	3.0	3.3	3.2	3.6
σ	**1.07**	1.0	1.2	1.4	1.4	0.0	1.1	1.1	1.2
$σ^2$	**1.15**	1.0	1.4	1.8	2.0	0.0	1.3	1.2	1.3





3.12(mean) F6 t-ocean

	1st			2nd			both		
∅	**3.12**	3.1	3.3	3.5	3.4	4.0	3.2	3.1	3.3
σ	**0.96**	0.9	1.1	1.4	1.4	0.0	1.0	1.0	1.1
$σ^2$	**0.93**	0.8	1.2	1.9	2.0	0.0	1.1	1.1	1.2

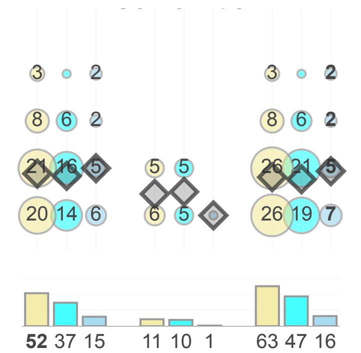


F1 - Expo 1970 Fuji Corporate Pavilion (Osaka)

(page 2/2)

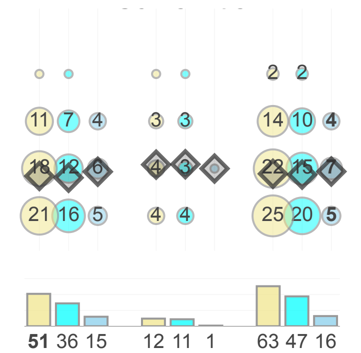
1.88(mean) G2 c-hyundai

	1st			2nd			both		
Ø	**1.88**	1.8	2.0	1.5	1.5	1.0	1.8	1.8	1.9
σ	**0.88**	0.8	1.1	0.5	0.5	0.0	0.8	0.8	1.1
σ²	**0.77**	0.6	1.1	0.3	0.3	0.0	0.7	0.6	1.1



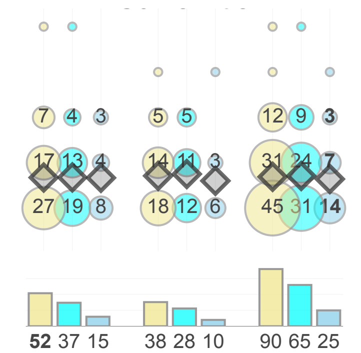
1.84(mean) H1 emp-n-cl

	1st			2nd			both		
Ø	**1.84**	1.8	1.9	2.1	2.1	2.0	1.9	1.9	1.9
σ	**0.83**	0.9	0.8	1.0	1.0	0.0	0.9	0.9	0.8
σ²	**0.69**	0.7	0.6	1.0	1.1	0.0	0.7	0.8	0.6



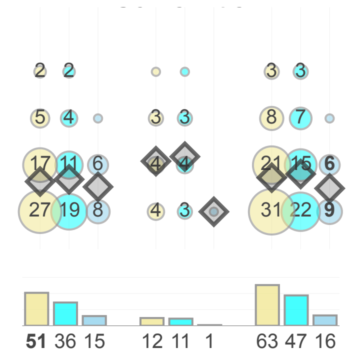
1.67(mean) G1 emp-n-su67

	1st			2nd			both		
Ø	**1.67**	1.7	1.7	1.7	1.8	1.6	1.7	1.7	1.6
σ	**0.86**	0.9	0.8	0.8	0.8	1.0	0.8	0.8	0.9
σ²	**0.73**	0.8	0.7	0.6	0.6	0.9	0.7	0.7	0.7



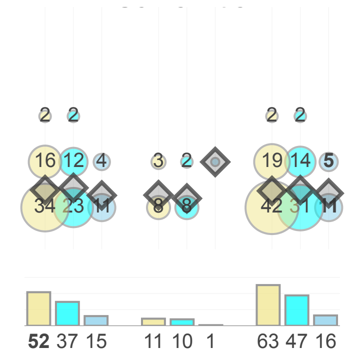
1.65(mean) H2 emp-c-info

	1st			2nd			both		
Ø	**1.65**	1.7	1.5	2.1	2.2	1.0	1.7	1.8	1.5
σ	**0.82**	0.9	0.6	1.0	1.0	0.0	0.9	0.9	0.6
σ²	**0.67**	0.8	0.4	1.0	1.0	0.0	0.7	0.9	0.4



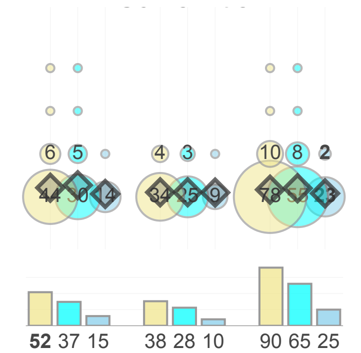
1.38(mean) G3 host-de

	1st			2nd			both		
Ø	**1.38**	1.4	1.3	1.3	1.2	2.0	1.4	1.4	1.3
σ	**0.57**	0.6	0.5	0.5	0.4	0.0	0.5	0.6	0.5
σ²	**0.32**	0.4	0.2	0.2	0.2	0.0	0.3	0.3	0.2



1.21(mean) E1 host-ca

	1st			2nd			both		
Ø	**1.21**	1.3	1.1	1.1	1.1	1.1	1.2	1.2	1.1
σ	**0.57**	0.7	0.3	0.3	0.3	0.3	0.5	0.5	0.3
σ²	**0.33**	0.4	0.1	0.1	0.1	0.1	0.2	0.3	0.1

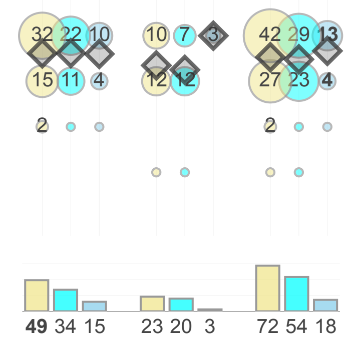


F2 - Expo 2010 Japan Pavilion (Shanghai)

(page 1/2)

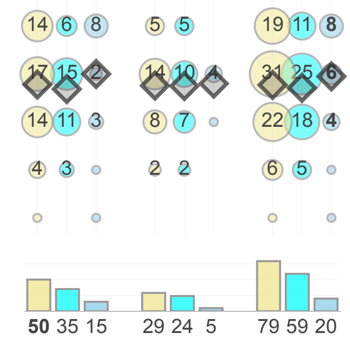
4.61(mean) F5 c-aviation

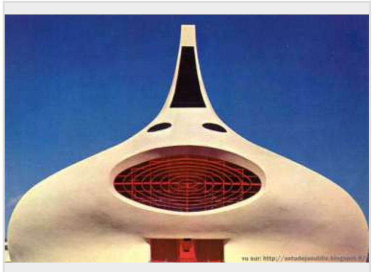
	1st			2nd			both		
Ø	**4.61**	4.6	4.6	4.3	4.3	5.0	4.5	4.5	4.7
σ	**0.57**	0.6	0.6	0.7	0.7	0.0	0.6	0.6	0.6
σ²	**0.33**	0.3	0.4	0.5	0.5	0.0	0.4	0.4	0.4



3.78(mean) F4 emp-t-hope

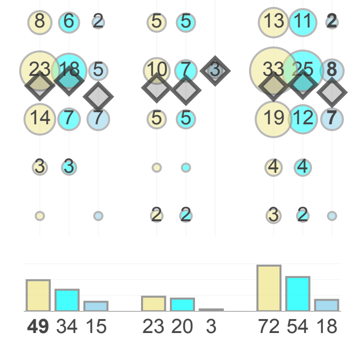
	1st			2nd			both		
Ø	**3.78**	3.7	4.0	3.8	3.8	3.8	3.8	3.7	4.0
σ	**1.02**	0.9	1.3	0.8	0.9	0.4	0.9	0.9	1.1
σ²	**1.03**	0.8	1.7	0.7	0.8	0.2	0.9	0.8	1.3

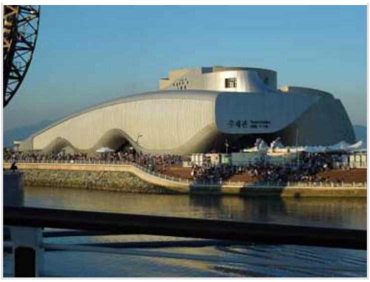




3.69(mean) F7 emp-c-gas

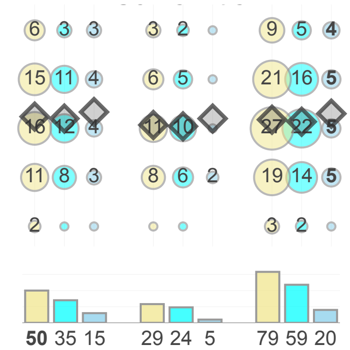
	1st			2nd			both		
Ø	**3.69**	3.8	3.5	3.7	3.6	4.0	3.7	3.7	3.6
σ	**0.89**	0.8	1.0	1.2	1.2	0.0	1.0	1.0	0.9
σ²	**0.80**	0.7	1.0	1.3	1.5	0.0	1.0	1.0	0.8





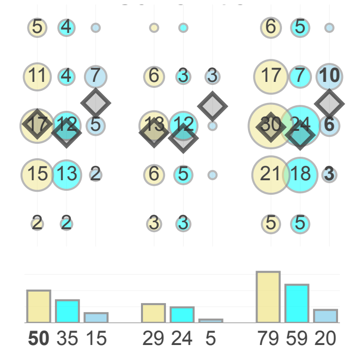
3.24(mean) F6 t-ocean

	1st			2nd			both		
Ø	**3.24**	3.2	3.3	3.1	3.0	3.2	3.2	3.1	3.3
σ	**1.06**	1.0	1.2	1.0	1.0	1.3	1.0	1.0	1.2
σ²	**1.12**	1.0	1.5	1.1	1.0	1.7	1.1	1.0	1.5



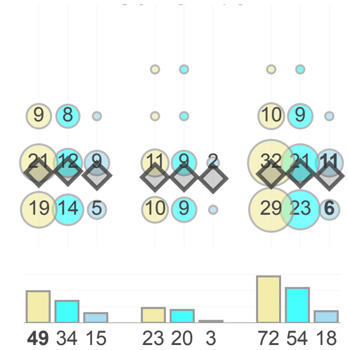
3.04(mean) E4 emp-n-sa

	1st			2nd			both		
Ø	**3.04**	2.9	3.5	2.9	2.8	3.4	3.0	2.8	3.5
σ	**1.05**	1.1	0.8	1.0	1.0	0.9	1.0	1.0	0.8
σ²	**1.10**	1.2	0.7	1.0	1.0	0.8	1.1	1.1	0.7



1.80(mean) E3 c-chemical

	1st			2nd			both		
Ø	**1.80**	1.8	1.7	1.7	1.7	1.7	1.8	1.8	1.7
σ	**0.74**	0.8	0.6	0.8	0.8	0.6	0.7	0.8	0.6
σ²	**0.54**	0.6	0.4	0.6	0.6	0.3	0.5	0.6	0.3

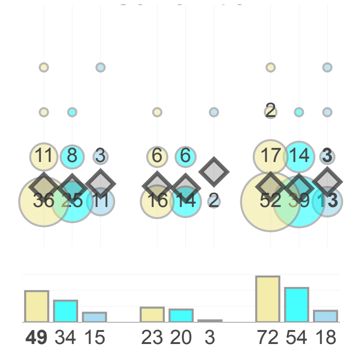


F2 - Expo 2010 Japan Pavilion (Shanghai)

(page 2/2)

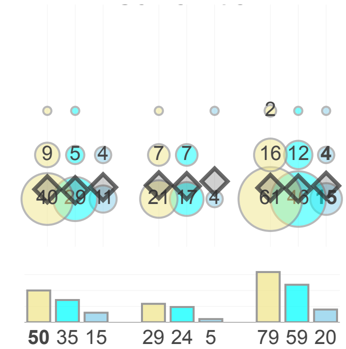
1.33(mean) G3 host-de

	1st			2nd			both		
Ø	**1.33**	1.3	1.4	1.3	1.3	1.7	1.3	1.3	1.4
σ	**0.63**	0.5	0.8	0.6	0.5	1.2	0.6	0.5	0.9
σ²	**0.39**	0.3	0.7	0.3	0.2	1.3	0.4	0.3	0.7



1.22(mean) G2 c-hyundai

	1st			2nd			both		
Ø	**1.22**	1.2	1.3	1.3	1.3	1.4	1.3	1.2	1.3
σ	**0.46**	0.5	0.5	0.5	0.5	0.9	0.5	0.5	0.6
σ²	**0.22**	0.2	0.2	0.3	0.2	0.8	0.2	0.2	0.3

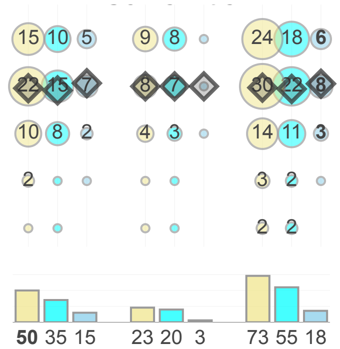


F3 - Expo 2000 Japan Pavilion (Hannover)

(page 1/2)

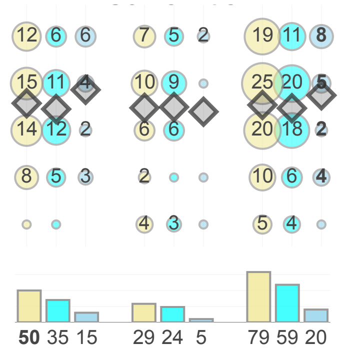
3.96(mean) F5 c-aviation

	1st			2nd			both		
Ø	**3.96**	3.9	4.1	4.0	4.0	4.0	4.0	3.9	4.1
σ	**0.92**	1.0	0.9	1.1	1.1	1.0	1.0	1.0	0.9
σ²	**0.86**	0.9	0.8	1.2	1.3	1.0	0.9	1.0	0.8



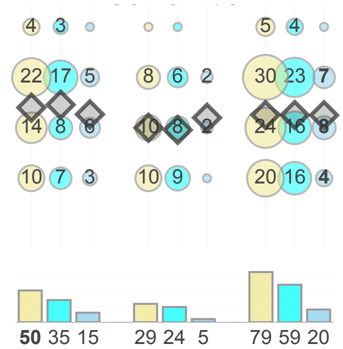
3.58(mean) F4 emp-t-hope

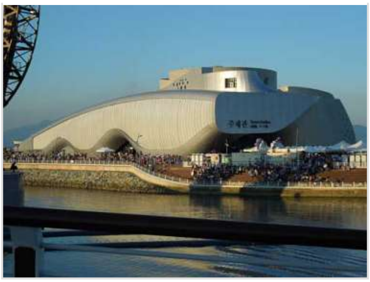
	1st			2nd			both		
Ø	**3.58**	3.5	3.9	3.5	3.5	3.4	3.5	3.5	3.8
σ	**1.09**	1.0	1.2	1.3	1.3	1.8	1.2	1.1	1.3
σ²	**1.19**	1.1	1.4	1.8	1.6	3.3	1.4	1.3	1.8



3.40(mean) F2 emp-n-jp10

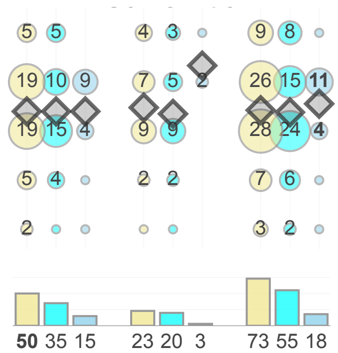
	1st			2nd			both		
Ø	**3.40**	3.5	3.3	3.0	3.0	3.2	3.3	3.3	3.3
σ	**0.90**	0.9	0.9	0.9	0.9	0.8	0.9	0.9	0.9
σ²	**0.82**	0.8	0.8	0.8	0.8	0.7	0.8	0.9	0.7

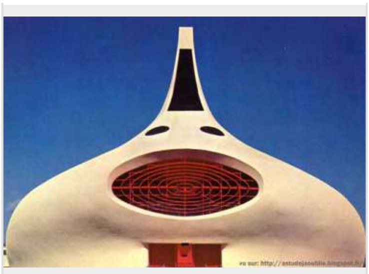




3.40(mean) F6 t-ocean

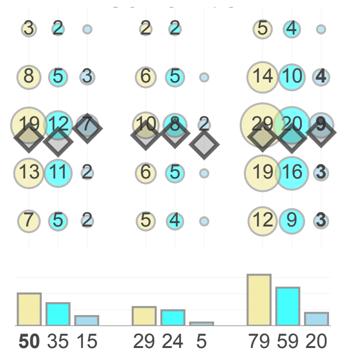
	1st			2nd			both		
Ø	**3.40**	3.4	3.4	3.5	3.4	4.3	3.4	3.4	3.6
σ	**0.95**	1.0	0.9	1.0	1.0	0.6	1.0	1.0	0.9
σ²	**0.90**	1.0	0.8	1.1	1.1	0.3	0.9	1.0	0.8





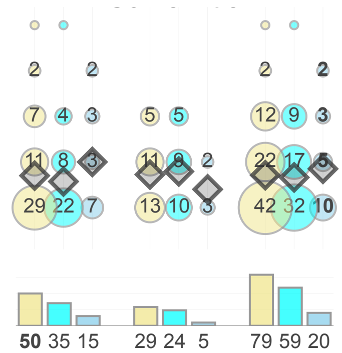
2.74(mean) F7 emp-c-gas

	1st			2nd			both		
Ø	**2.74**	2.7	2.9	2.8	2.8	2.6	2.8	2.7	2.9
σ	**1.08**	1.1	1.1	1.2	1.2	1.1	1.1	1.1	1.1
σ²	**1.18**	1.2	1.2	1.4	1.4	1.3	1.2	1.3	1.2



1.70(mean) H2 emp-c-info

	1st			2nd			both		
Ø	**1.70**	1.6	2.0	1.7	1.8	1.4	1.7	1.7	1.9
σ	**0.99**	0.9	1.1	0.8	0.8	0.5	0.9	0.9	1.0
σ²	**0.99**	0.8	1.3	0.6	0.6	0.3	0.8	0.7	1.1

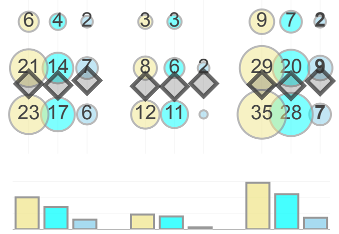


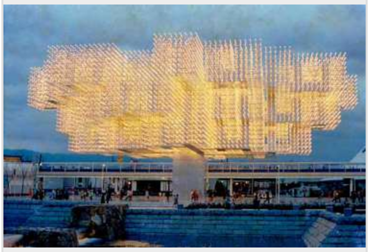
F3 - Expo 2000 Japan Pavilion (Hannover)

(page 2/2)

1.66(mean) G3 host-de

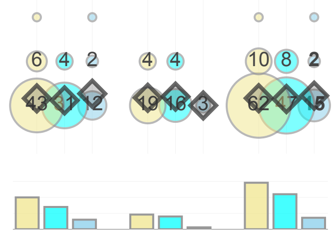
	1st			2nd			both		
Ø	**1.66**	1.6	1.7	1.6	1.6	1.7	1.6	1.6	1.7
σ	**0.69**	0.7	0.7	0.7	0.8	0.6	0.7	0.7	0.7
σ^2	**0.47**	0.5	0.5	0.5	0.6	0.3	0.5	0.5	0.4





1.16(mean) E5 emp-n-ch

	1st			2nd			both		
Ø	**1.16**	1.1	1.3	1.2	1.2	1.0	1.2	1.1	1.2
σ	**0.42**	0.3	0.6	0.4	0.4	0.0	0.4	0.4	0.5
σ^2	**0.18**	0.1	0.4	0.2	0.2	0.0	0.2	0.1	0.3

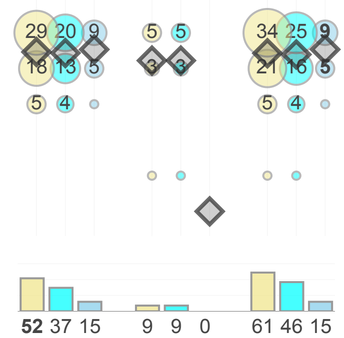


G1 - Expo 1967 Soviet Union Pavilion (Montreal)

(page 1/2)

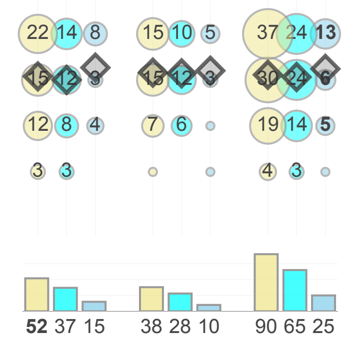
4.46(mean) G5 emp-n-it67

	1st			2nd			both		
Ø	**4.46**	4.4	4.5	4.2	4.2	0.0	4.4	4.4	4.5
σ	**0.67**	0.7	0.6	1.3	1.3	0.0	0.8	0.8	0.6
σ²	**0.45**	0.5	0.4	1.7	1.7	0.0	0.6	0.7	0.4



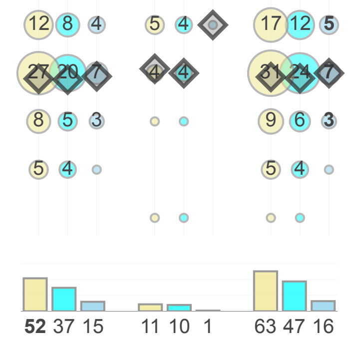
4.08(mean) G3 host-de

	1st			2nd			both		
Ø	**4.08**	4.0	4.3	4.2	4.1	4.2	4.1	4.1	4.2
σ	**0.95**	1.0	0.9	0.8	0.8	1.0	0.9	0.9	0.9
σ²	**0.90**	0.9	0.8	0.7	0.6	1.1	0.8	0.8	0.9



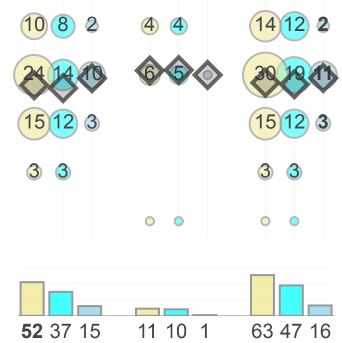
3.88(mean) G7 c-textiles

	1st			2nd			both		
Ø	**3.88**	3.9	3.9	4.1	4.0	5.0	3.9	3.9	4.0
σ	**0.88**	0.9	0.9	1.2	1.2	0.0	0.9	1.0	0.9
σ²	**0.77**	0.8	0.8	1.5	1.6	0.0	0.9	0.9	0.8



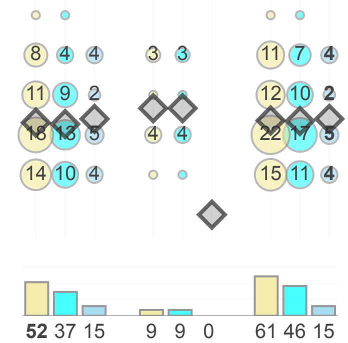
3.79(mean) G6 host-pt

	1st			2nd			both		
Ø	**3.79**	3.7	3.9	4.1	4.1	4.0	3.8	3.8	3.9
σ	**0.82**	0.9	0.6	1.1	1.2	0.0	0.9	1.0	0.6
σ²	**0.68**	0.8	0.4	1.3	1.4	0.0	0.8	0.9	0.3



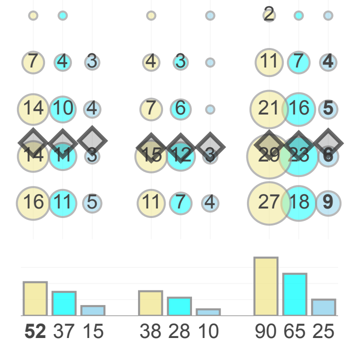
2.31(mean) E1 host-ca

	1st			2nd			both		
Ø	**2.31**	2.3	2.4	2.7	2.7	0.0	2.4	2.3	2.4
σ	**1.09**	1.1	1.2	1.1	1.1	0.0	1.1	1.1	1.2
σ²	**1.20**	1.1	1.4	1.3	1.3	0.0	1.2	1.2	1.4



2.29(mean) G2 c-hyundai

	1st			2nd			both		
Ø	**2.29**	2.3	2.3	2.2	2.2	2.2	2.2	2.2	2.3
σ	**1.11**	1.1	1.2	1.1	0.9	1.4	1.1	1.0	1.2
σ²	**1.23**	1.2	1.4	1.1	0.9	2.0	1.2	1.1	1.5

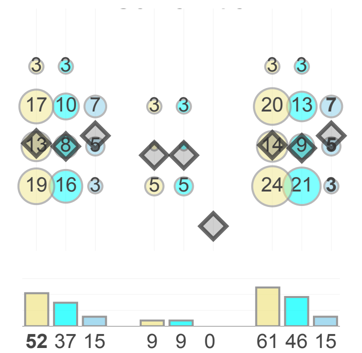


G1 - Expo 1967 Soviet Union Pavilion (Montreal)

(page 2/2)

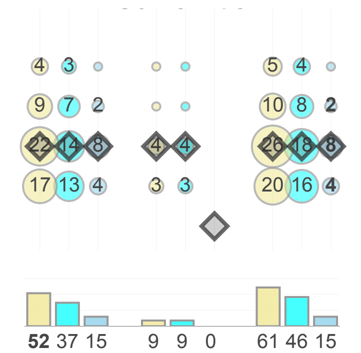
2.08(mean) G4 emp-n-br

	1st			2nd			both		
Ø	**2.08**	2.0	2.3	1.8	1.8	0.0	2.0	2.0	2.3
σ	**0.97**	1.0	0.8	1.0	1.0	0.0	1.0	1.0	0.8
σ²	**0.94**	1.1	0.6	0.9	0.9	0.0	0.9	1.0	0.6



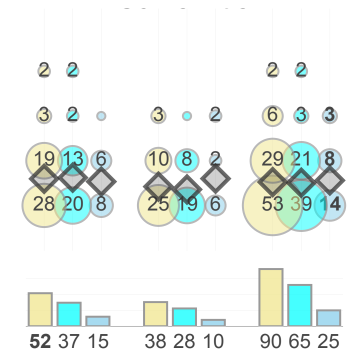
2.00(mean) E2 host-cn

	1st			2nd			both		
Ø	**2.00**	2.0	2.0	2.0	2.0	0.0	2.0	2.0	2.0
σ	**0.91**	0.9	0.8	1.0	1.0	0.0	0.9	0.9	0.8
σ²	**0.82**	0.9	0.7	1.0	1.0	0.0	0.8	0.9	0.7



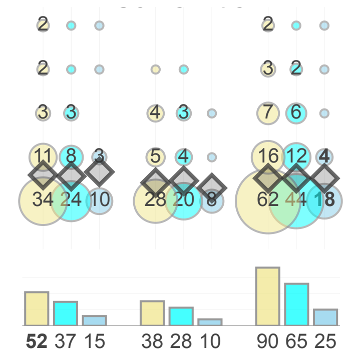
1.60(mean) H1 emp-n-cl

	1st			2nd			both		
Ø	**1.60**	1.6	1.5	1.4	1.4	1.6	1.5	1.5	1.6
σ	**0.77**	0.8	0.6	0.6	0.6	0.8	0.7	0.7	0.7
σ²	**0.60**	0.7	0.4	0.4	0.3	0.7	0.5	0.5	0.5



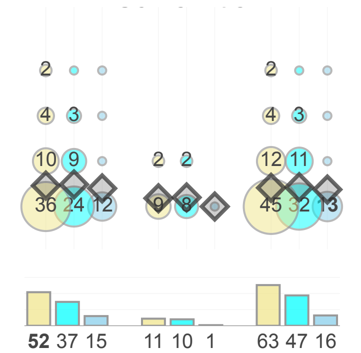
1.60(mean) F1 emp-c-fuji

	1st			2nd			both		
Ø	**1.60**	1.6	1.7	1.4	1.5	1.3	1.5	1.5	1.5
σ	**1.03**	1.0	1.2	0.8	0.8	0.7	0.9	0.9	1.0
σ²	**1.07**	0.9	1.5	0.6	0.7	0.5	0.9	0.8	1.1



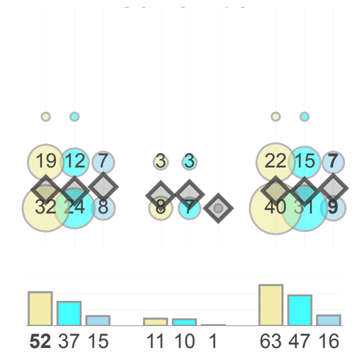
1.46(mean) H3 emp-n-au10

	1st			2nd			both		
Ø	**1.46**	1.5	1.4	1.2	1.2	1.0	1.4	1.4	1.4
σ	**0.80**	0.8	0.9	0.4	0.4	0.0	0.8	0.7	0.9
σ²	**0.65**	0.6	0.8	0.2	0.2	0.0	0.6	0.5	0.8



1.40(mean) H2 emp-c-info

	1st			2nd			both		
Ø	**1.40**	1.4	1.5	1.3	1.3	1.0	1.4	1.4	1.4
σ	**0.53**	0.5	0.5	0.5	0.5	0.0	0.5	0.5	0.5
σ²	**0.28**	0.3	0.3	0.2	0.2	0.0	0.3	0.3	0.3

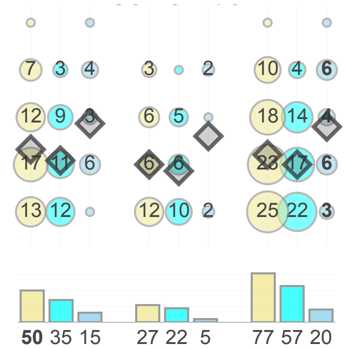


G2 - Expo 2012 Hyundai Corporate Pavilion (Yeosu)

(page 1/2)

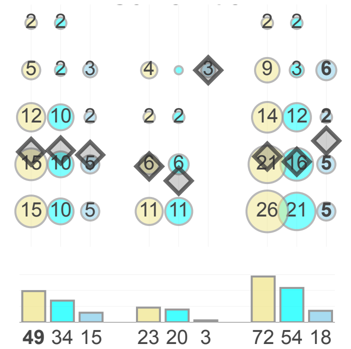
2.32(mean) H2 emp-c-info

	1st			2nd			both		
Ø	**2.32**	2.1	2.9	2.0	1.9	2.6	2.2	2.0	2.8
σ	**1.08**	1.0	1.1	1.1	0.9	1.5	1.1	1.0	1.2
σ²	**1.16**	1.0	1.3	1.2	0.9	2.3	1.2	0.9	1.4



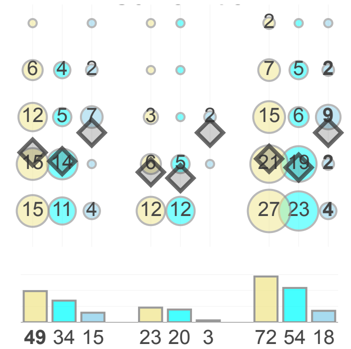
2.27(mean) H3 emp-n-au10

	1st			2nd			both		
Ø	**2.27**	2.3	2.2	2.0	1.7	4.0	2.2	2.1	2.5
σ	**1.13**	1.1	1.1	1.1	0.9	0.0	1.1	1.1	1.2
σ²	**1.28**	1.3	1.3	1.3	0.8	0.0	1.3	1.2	1.6



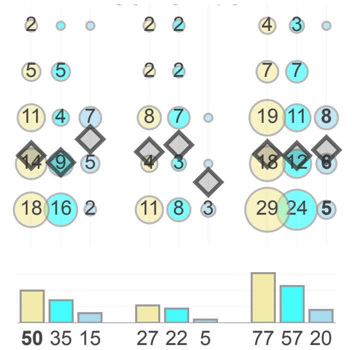
2.24(mean) F3 emp-n-jp00

	1st			2nd			both		
Ø	**2.24**	2.1	2.7	1.8	1.7	2.7	2.1	1.9	2.7
σ	**1.09**	1.0	1.2	1.1	1.1	0.6	1.1	1.0	1.1
σ²	**1.19**	1.0	1.5	1.2	1.3	0.3	1.2	1.1	1.3



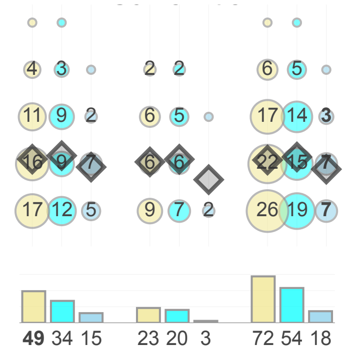
2.18(mean) G6 host-pt

	1st			2nd			both		
Ø	**2.18**	2.0	2.5	2.3	2.4	1.6	2.2	2.2	2.3
σ	**1.16**	1.2	1.0	1.3	1.3	0.9	1.2	1.3	1.0
σ²	**1.33**	1.4	1.0	1.7	1.8	0.8	1.4	1.6	1.1



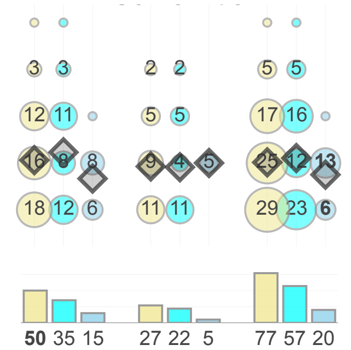
2.10(mean) G7 c-textiles

	1st			2nd			both		
Ø	**2.10**	2.2	1.9	2.0	2.1	1.7	2.1	2.1	1.9
σ	**1.05**	1.1	0.9	1.0	1.0	1.2	1.0	1.1	0.9
σ²	**1.09**	1.2	0.8	1.0	1.0	1.3	1.1	1.1	0.8



2.06(mean) G4 emp-n-br

	1st			2nd			both		
Ø	**2.06**	2.2	1.7	1.9	1.9	2.0	2.0	2.1	1.8
σ	**1.02**	1.1	0.6	1.0	1.1	0.0	1.0	1.1	0.6
σ²	**1.04**	1.2	0.4	0.9	1.1	0.0	1.0	1.2	0.3

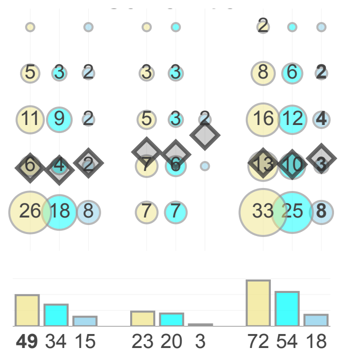


G2 - Expo 2012 Hyundai Corporate Pavilion (Yeosu)

(page 2/2)

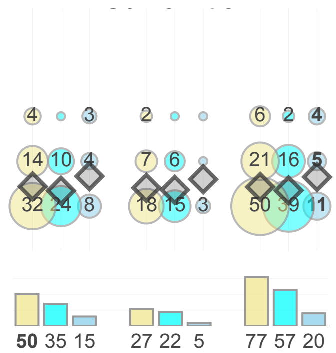
1.96(mean) G5 emp-n-it67

	1st			2nd			both		
Ø	**1.96**	1.9	2.1	2.3	2.3	2.7	2.1	2.0	2.2
σ	**1.17**	1.1	1.4	1.2	1.3	0.6	1.2	1.1	1.3
σ²	**1.37**	1.2	1.9	1.4	1.6	0.3	1.4	1.3	1.7



1.44(mean) E2 host-cn

	1st			2nd			both		
Ø	**1.44**	1.3	1.7	1.4	1.4	1.6	1.4	1.4	1.7
σ	**0.64**	0.5	0.8	0.6	0.6	0.9	0.6	0.6	0.8
σ²	**0.41**	0.3	0.7	0.4	0.3	0.8	0.4	0.3	0.7

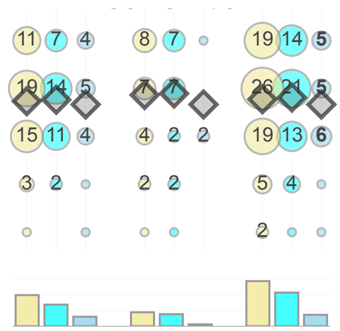


G3 - Expo 2000 Germany Host Pavilion (Hannover)

(page 1/2)

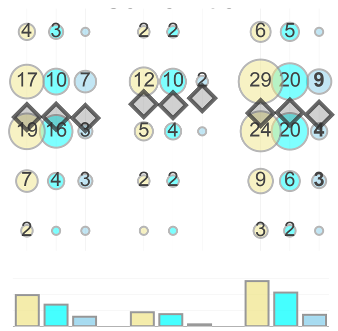
3.73(mean) G5 emp-n-it67

	1st			2nd			both		
Ø	**3.73**	3.8	3.7	3.9	3.9	3.7	3.8	3.8	3.7
σ	**0.95**	0.9	1.2	1.2	1.2	1.2	1.0	1.0	1.1
σ²	**0.91**	0.7	1.4	1.4	1.4	1.3	1.0	1.0	1.3



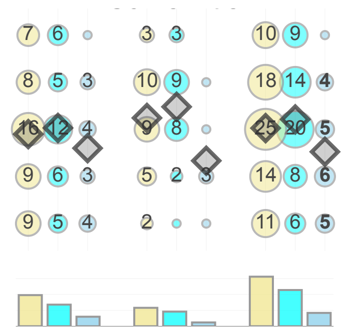
3.29(mean) G6 host-pt

	1st			2nd			both		
Ø	**3.29**	3.3	3.3	3.5	3.5	3.7	3.4	3.4	3.3
σ	**0.96**	0.9	1.1	1.0	1.0	0.6	1.0	0.9	1.0
σ²	**0.92**	0.8	1.2	0.9	1.0	0.3	0.9	0.9	1.1



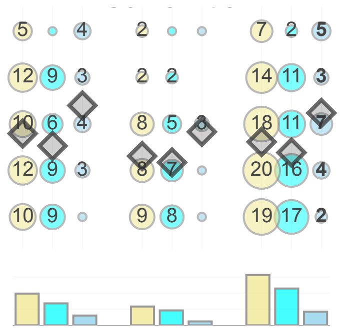
2.90(mean) G7 c-textiles

	1st			2nd			both		
Ø	**2.90**	3.0	2.6	3.2	3.5	2.3	3.0	3.2	2.5
σ	**1.29**	1.3	1.3	1.1	1.0	1.0	1.2	1.2	1.2
σ²	**1.68**	1.7	1.7	1.2	1.0	1.1	1.5	1.4	1.5



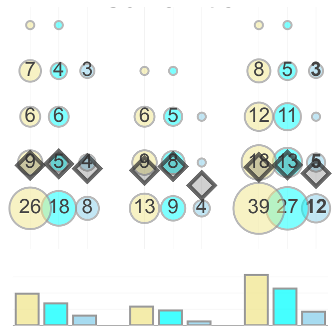
2.80(mean) G4 emp-n-br

	1st			2nd			both		
Ø	**2.80**	2.5	3.4	2.3	2.2	2.8	2.6	2.4	3.2
σ	**1.31**	1.2	1.3	1.2	1.2	1.3	1.3	1.2	1.3
σ²	**1.71**	1.5	1.7	1.4	1.3	1.8	1.6	1.5	1.7



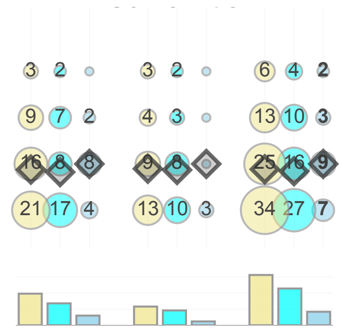
1.94(mean) G2 c-hyundai

	1st			2nd			both		
Ø	**1.94**	2.0	1.9	1.8	1.9	1.5	1.9	1.9	1.8
σ	**1.20**	1.2	1.2	0.9	0.9	0.8	1.1	1.1	1.1
σ²	**1.43**	1.5	1.4	0.8	0.8	0.7	1.2	1.2	1.2



1.88(mean) E2 host-cn

	1st			2nd			both		
Ø	**1.88**	1.8	2.0	1.9	1.9	2.0	1.9	1.8	2.0
σ	**0.93**	1.0	0.8	1.0	1.0	1.3	1.0	1.0	0.9
σ²	**0.86**	0.9	0.7	1.0	0.9	1.6	0.9	0.9	0.9

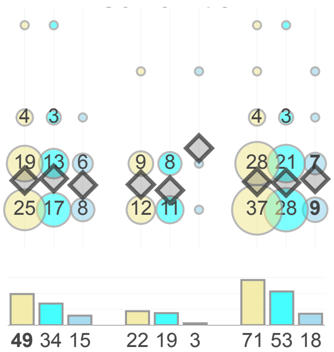


G3 - Expo 2000 Germany Host Pavilion (Hannover)

(page 2/2)

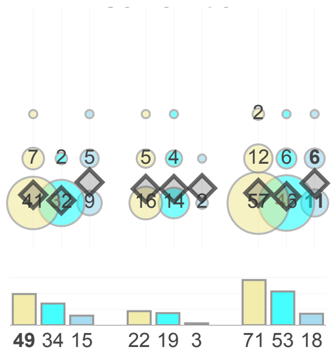
1.63(mean) H3 emp-n-au10

	1st			2nd			both		
Ø	**1.63**	1.7	1.5	1.5	1.4	2.3	1.6	1.6	1.7
σ	**0.81**	0.9	0.6	0.7	0.5	1.5	0.8	0.8	0.8
σ^2	**0.65**	0.8	0.4	0.5	0.3	2.3	0.6	0.6	0.7



1.18(mean) E3 c-chemical

	1st			2nd			both		
Ø	**1.18**	1.1	1.5	1.3	1.3	1.3	1.2	1.2	1.4
σ	**0.44**	0.2	0.6	0.6	0.6	0.6	0.5	0.4	0.6
σ^2	**0.19**	0.1	0.4	0.3	0.3	0.3	0.2	0.2	0.4

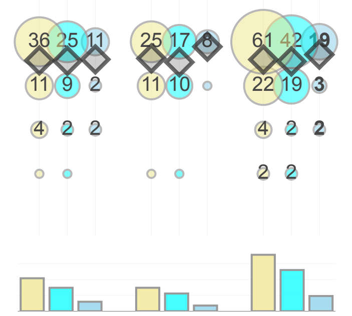


H1 - Expo 2010 Chile Pavilion (Shanghai)

(page 1/2)

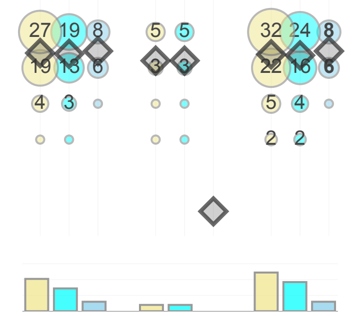
4.58(mean) H3 emp-n-au10

	1st			2nd			both		
Ø	**4.58**	4.6	4.6	4.6	4.5	4.9	4.6	4.6	4.7
σ	**0.72**	0.7	0.7	0.6	0.7	0.3	0.7	0.7	0.6
σ^2	**0.52**	0.5	0.5	0.4	0.5	0.1	0.5	0.5	0.4



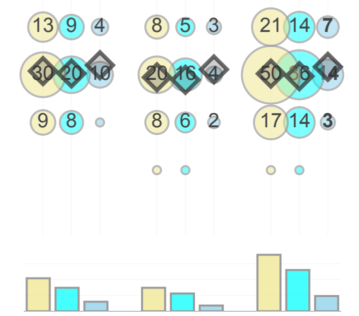
4.41(mean) H4 c-private

	1st			2nd			both		
Ø	**4.41**	4.4	4.5	4.2	4.2	0.0	4.4	4.3	4.5
σ	**0.73**	0.8	0.6	1.0	1.0	0.0	0.8	0.8	0.6
σ^2	**0.53**	0.6	0.4	1.1	1.1	0.0	0.6	0.7	0.4



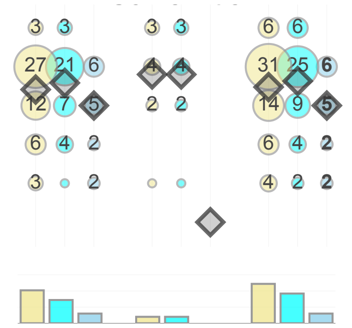
4.08(mean) H2 emp-c-info

	1st			2nd			both		
Ø	**4.08**	4.0	4.2	3.9	3.9	4.1	4.0	4.0	4.2
σ	**0.65**	0.7	0.6	0.7	0.7	0.8	0.7	0.7	0.6
σ^2	**0.43**	0.5	0.3	0.6	0.5	0.6	0.5	0.5	0.4



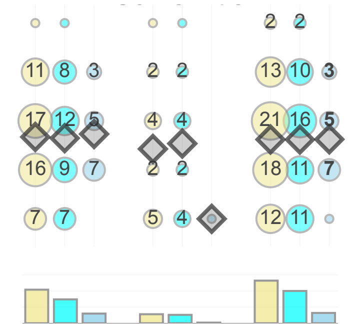
3.41(mean) H5 emp-n-es

	1st			2nd			both		
Ø	**3.41**	3.6	3.0	3.8	3.8	0.0	3.5	3.6	3.0
σ	**0.98**	0.9	1.1	1.2	1.2	0.0	1.0	1.0	1.1
σ^2	**0.97**	0.8	1.1	1.5	1.5	0.0	1.1	0.9	1.1



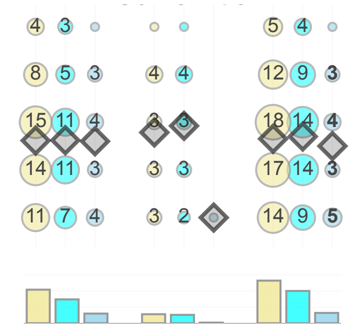
2.67(mean) E3 c-chemical

	1st			2nd			both		
Ø	**2.67**	2.6	2.7	2.4	2.5	1.0	2.6	2.6	2.6
σ	**1.02**	1.1	0.8	1.3	1.3	0.0	1.1	1.2	0.9
σ^2	**1.05**	1.2	0.6	1.8	1.8	0.0	1.2	1.3	0.8



2.62(mean) H7 emp-n-hu

	1st			2nd			both		
Ø	**2.62**	2.6	2.6	2.8	2.9	1.0	2.7	2.7	2.5
σ	**1.21**	1.2	1.3	1.3	1.3	0.0	1.2	1.2	1.3
σ^2	**1.46**	1.4	1.7	1.7	1.6	0.0	1.5	1.4	1.7

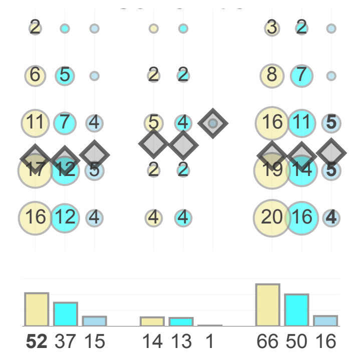


H1 - Expo 2010 Chile Pavilion (Shanghai)

(page 2/2)

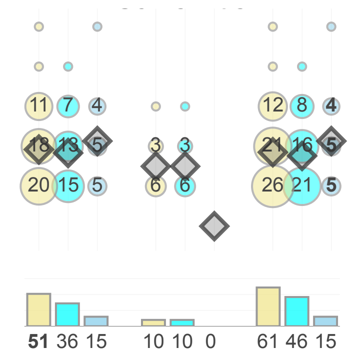
2.25(mean) H6 t-futuro

	1st			2nd			both		
Ø	**2.25**	2.2	2.3	2.6	2.5	3.0	2.3	2.3	2.4
σ	**1.14**	1.1	1.2	1.3	1.3	0.0	1.2	1.2	1.1
σ²	**1.29**	1.3	1.4	1.6	1.8	0.0	1.4	1.4	1.3



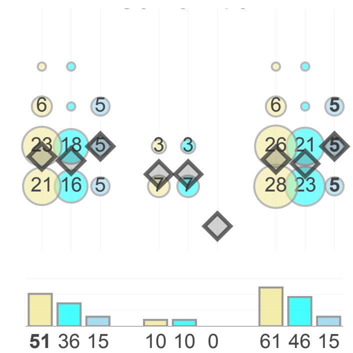
1.92(mean) F1 emp-c-fuji

	1st			2nd			both		
Ø	**1.92**	1.8	2.1	1.5	1.5	0.0	1.9	1.8	2.1
σ	**0.93**	0.8	1.1	0.7	0.7	0.0	0.9	0.8	1.1
σ²	**0.87**	0.7	1.3	0.5	0.5	0.0	0.8	0.7	1.3



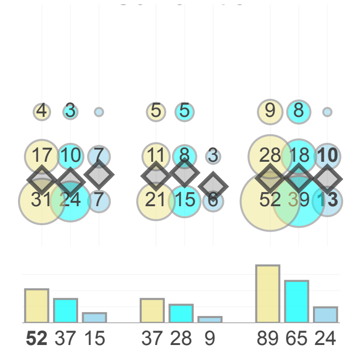
1.75(mean) F2 emp-n-jp10

	1st			2nd			both		
Ø	**1.75**	1.6	2.0	1.3	1.3	0.0	1.7	1.6	2.0
σ	**0.74**	0.7	0.8	0.5	0.5	0.0	0.7	0.7	0.8
σ²	**0.55**	0.5	0.7	0.2	0.2	0.0	0.5	0.4	0.7



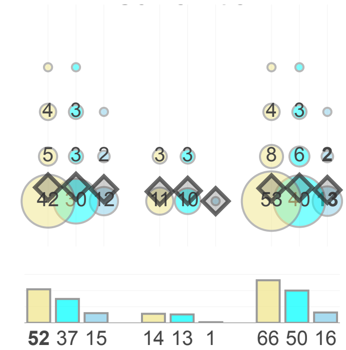
1.48(mean) G1 emp-n-su67

	1st			2nd			both		
Ø	**1.48**	1.4	1.6	1.6	1.6	1.3	1.5	1.5	1.5
σ	**0.64**	0.6	0.6	0.7	0.8	0.5	0.7	0.7	0.6
σ²	**0.41**	0.4	0.4	0.5	0.6	0.3	0.5	0.5	0.3



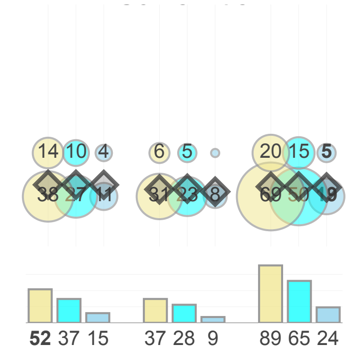
1.31(mean) E2 host-cn

	1st			2nd			both		
Ø	**1.31**	1.3	1.3	1.2	1.2	1.0	1.3	1.3	1.3
σ	**0.70**	0.7	0.6	0.4	0.4	0.0	0.7	0.7	0.6
σ²	**0.49**	0.6	0.4	0.2	0.2	0.0	0.4	0.5	0.3



1.27(mean) E1 host-ca

	1st			2nd			both		
Ø	**1.27**	1.3	1.3	1.2	1.2	1.1	1.2	1.2	1.2
σ	**0.45**	0.5	0.5	0.4	0.4	0.3	0.4	0.4	0.4
σ²	**0.20**	0.2	0.2	0.1	0.2	0.1	0.2	0.2	0.2

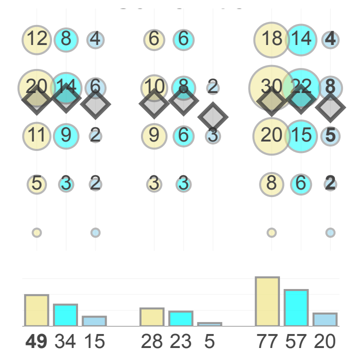


H2 - Expo 2010 Info Communication Corp. Pav. (Shanghai)

(page 1/2)

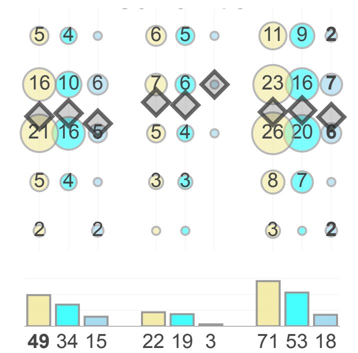
3.76(mean) H4 c-private

	1st			2nd			both		
Ø	**3.76**	3.8	3.7	3.7	3.7	3.4	3.7	3.8	3.6
σ	**1.01**	0.9	1.2	0.9	1.0	0.5	1.0	0.9	1.1
$σ^2$	**1.02**	0.8	1.5	0.9	1.0	0.3	1.0	0.9	1.2



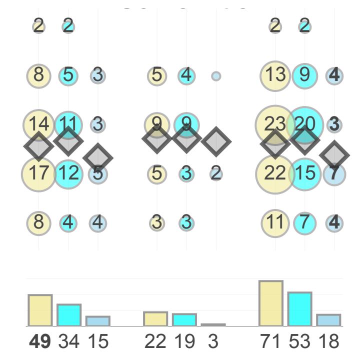
3.35(mean) H5 emp-n-es

	1st			2nd			both		
Ø	**3.35**	3.4	3.2	3.6	3.6	4.0	3.4	3.5	3.3
σ	**0.95**	0.9	1.1	1.2	1.2	1.0	1.0	1.0	1.1
$σ^2$	**0.90**	0.7	1.3	1.4	1.5	1.0	1.0	1.0	1.3



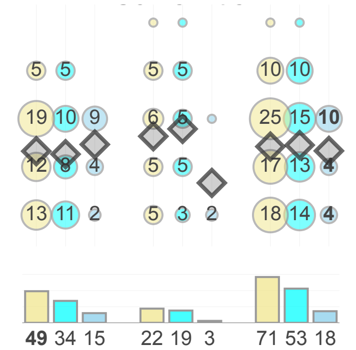
2.57(mean) E3 c-chemical

	1st			2nd			both		
Ø	**2.57**	2.7	2.3	2.7	2.7	2.7	2.6	2.7	2.4
σ	**1.08**	1.1	1.1	1.0	1.0	1.2	1.0	1.0	1.1
$σ^2$	**1.17**	1.1	1.2	1.0	1.0	1.3	1.1	1.1	1.2



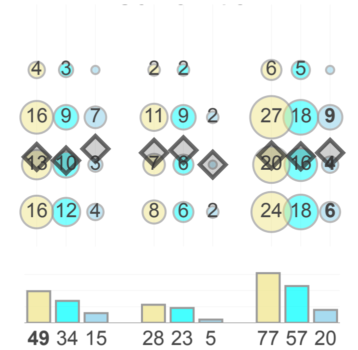
2.33(mean) H7 emp-n-hu

	1st			2nd			both		
Ø	**2.33**	2.3	2.5	2.6	2.8	1.7	2.4	2.5	2.3
σ	**0.99**	1.1	0.7	1.2	1.2	1.2	1.1	1.1	0.8
$σ^2$	**0.97**	1.2	0.6	1.5	1.4	1.3	1.1	1.3	0.7



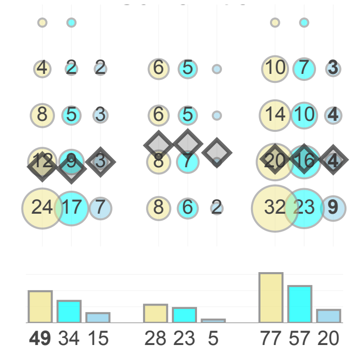
2.16(mean) F2 emp-n-jp10

	1st			2nd			both		
Ø	**2.16**	2.1	2.3	2.3	2.3	2.0	2.2	2.2	2.3
σ	**0.99**	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
$σ^2$	**0.97**	1.0	1.0	0.9	0.9	1.0	0.9	1.0	0.9



1.90(mean) H6 t-futuro

	1st			2nd			both		
Ø	**1.90**	1.9	2.0	2.4	2.4	2.2	2.1	2.1	2.1
σ	**1.08**	1.1	1.1	1.1	1.1	1.3	1.1	1.1	1.1
$σ^2$	**1.18**	1.2	1.3	1.3	1.2	1.7	1.2	1.2	1.3

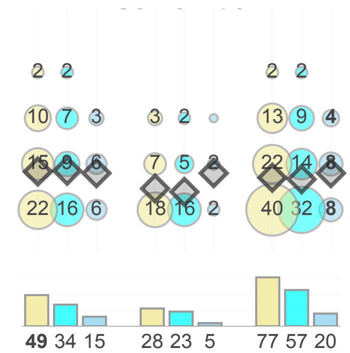


H2 - Expo 2010 Info Communication Corp. Pav. (Shanghai)

(page 2/2)

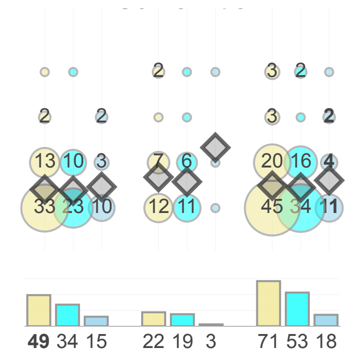
1.84(mean) G4 emp-n-br

	1st			2nd			both		
Ø	**1.84**	1.9	1.8	1.5	1.4	1.8	1.7	1.7	1.8
σ	**0.90**	1.0	0.8	0.7	0.7	0.8	0.8	0.9	0.8
σ^2	**0.81**	0.9	0.6	0.5	0.4	0.7	0.7	0.8	0.6



1.41(mean) G3 host-de

	1st			2nd			both		
Ø	**1.41**	1.4	1.5	1.7	1.6	2.3	1.5	1.5	1.6
σ	**0.67**	0.7	0.7	0.9	0.8	1.5	0.8	0.7	0.9
σ^2	**0.45**	0.4	0.6	0.9	0.7	2.3	0.6	0.5	0.8

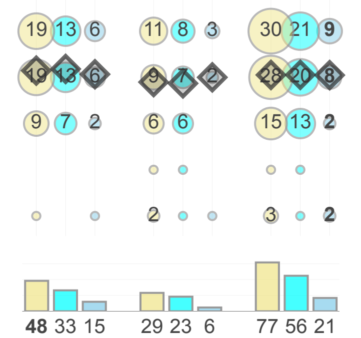


H3 - Expo 2010 Australia Pavilion (Shanghai)

(page 1/2)

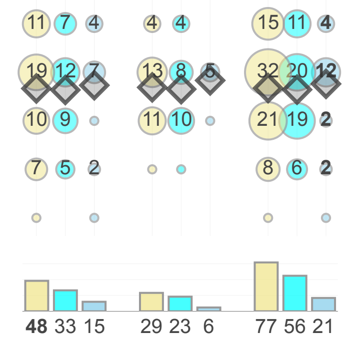
4.15(mean) H4 c-private

	1st			2nd			both		
Ø	**4.15**	4.2	4.1	3.9	3.9	4.0	4.1	4.1	4.0
σ	**0.87**	0.8	1.1	1.2	1.1	1.5	1.0	0.9	1.2
σ²	**0.77**	0.6	1.2	1.4	1.2	2.4	1.0	0.9	1.4



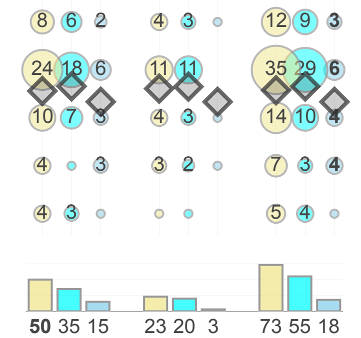
3.67(mean) H2 emp-c-info

	1st			2nd			both		
Ø	**3.67**	3.6	3.7	3.7	3.7	3.8	3.7	3.6	3.8
σ	**1.06**	1.0	1.2	0.8	0.8	0.4	1.0	0.9	1.0
σ²	**1.12**	1.0	1.5	0.6	0.7	0.2	0.9	0.9	1.1



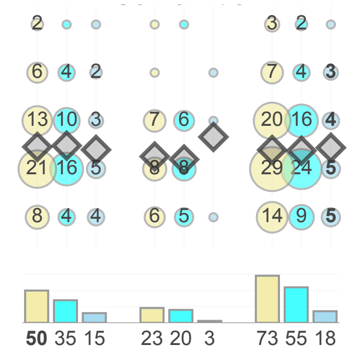
3.56(mean) H5 emp-n-es

	1st			2nd			both		
Ø	**3.56**	3.7	3.3	3.6	3.7	3.3	3.6	3.7	3.3
σ	**1.11**	1.1	1.2	1.1	1.0	1.5	1.1	1.1	1.2
σ²	**1.23**	1.2	1.4	1.2	1.1	2.3	1.2	1.1	1.4



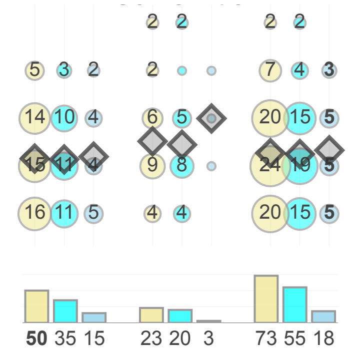
2.46(mean) F3 emp-n-jp00

	1st			2nd			both		
Ø	**2.46**	2.5	2.4	2.3	2.2	2.7	2.4	2.4	2.4
σ	**1.03**	1.0	1.2	1.1	1.0	1.5	1.0	1.0	1.2
σ²	**1.07**	0.9	1.5	1.1	1.0	2.3	1.1	0.9	1.6



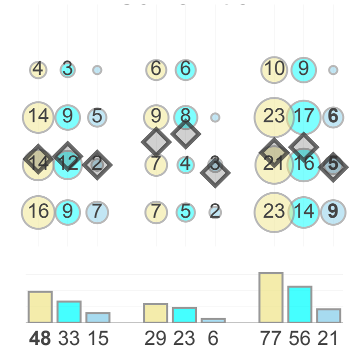
2.16(mean) H6 t-futuro

	1st			2nd			both		
Ø	**2.16**	2.1	2.2	2.5	2.5	3.0	2.3	2.3	2.3
σ	**1.00**	1.0	1.1	1.2	1.2	1.0	1.1	1.1	1.1
σ²	**0.99**	0.9	1.2	1.4	1.4	1.0	1.1	1.1	1.2



2.13(mean) H7 emp-n-hu

	1st			2nd			both		
Ø	**2.13**	2.2	2.0	2.5	2.7	1.8	2.3	2.4	2.0
σ	**0.98**	1.0	1.1	1.1	1.1	0.8	1.0	1.0	1.0
σ²	**0.96**	0.9	1.1	1.2	1.2	0.6	1.1	1.1	0.9

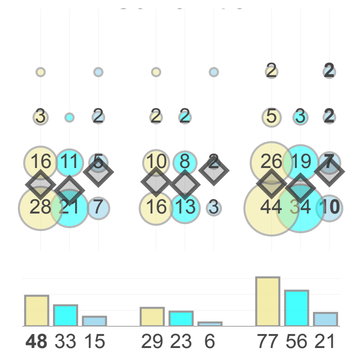


H3 - Expo 2010 Australia Pavilion (Shanghai)

(page 2/2)

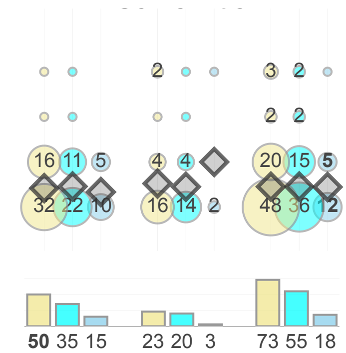
1.52(mean) F2 emp-n-jp10

	1st			2nd			both		
Ø	**1.52**	1.4	1.8	1.6	1.5	1.8	1.5	1.4	1.8
σ	**0.71**	0.6	0.9	0.8	0.7	1.2	0.7	0.6	1.0
σ²	**0.51**	0.3	0.9	0.6	0.4	1.4	0.5	0.4	1.0



1.42(mean) G5 emp-n-it67

	1st			2nd			both		
Ø	**1.42**	1.5	1.3	1.5	1.5	2.0	1.5	1.5	1.4
σ	**0.64**	0.7	0.5	0.9	0.8	1.7	0.7	0.7	0.8
σ²	**0.41**	0.5	0.2	0.9	0.7	3.0	0.6	0.5	0.6

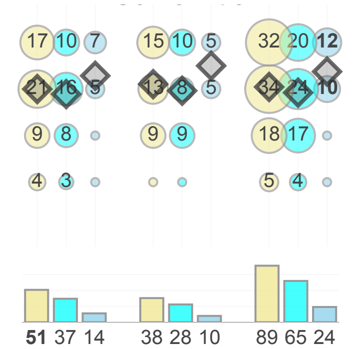


S1 - Expo 2010 France Pavilion (Shanghai)

(page 1/2)

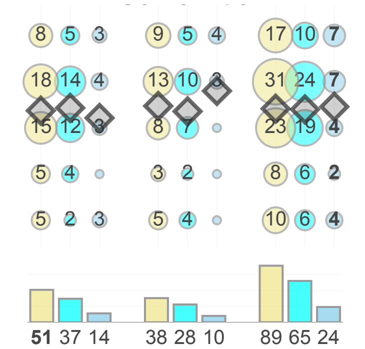
4.00(mean) T1 c-samsung

	1st			2nd			both		
Ø	**4.00**	3.9	4.3	4.1	4.0	4.5	4.0	3.9	4.4
σ	**0.92**	0.9	0.9	0.9	0.9	0.5	0.9	0.9	0.8
σ²	**0.84**	0.8	0.8	0.7	0.9	0.3	0.8	0.8	0.6



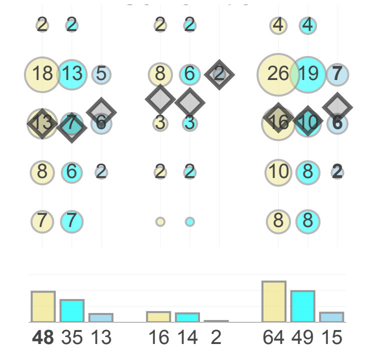
3.37(mean) S3 emp-n-cz

	1st			2nd			both		
Ø	**3.37**	3.4	3.2	3.5	3.4	3.8	3.4	3.4	3.5
σ	**1.17**	1.0	1.5	1.3	1.3	1.4	1.2	1.1	1.4
σ²	**1.36**	1.1	2.2	1.7	1.6	2.0	1.5	1.3	2.1



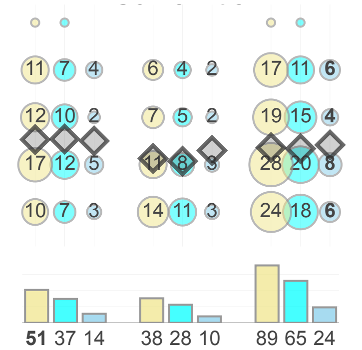
3.00(mean) U1 emp-n-nl67

	1st			2nd			both		
Ø	**3.00**	2.9	3.2	3.5	3.4	4.0	3.1	3.1	3.3
σ	**1.15**	1.3	0.7	1.1	1.2	0.0	1.1	1.2	0.7
σ²	**1.32**	1.6	0.5	1.2	1.3	0.0	1.3	1.6	0.5



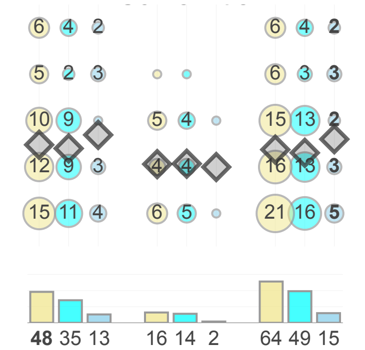
2.53(mean) S2 emp-n-fi

	1st			2nd			both		
Ø	**2.53**	2.5	2.5	2.1	2.1	2.3	2.4	2.3	2.4
σ	**1.10**	1.1	1.2	1.1	1.1	1.2	1.1	1.1	1.1
σ²	**1.21**	1.2	1.3	1.2	1.2	1.3	1.2	1.2	1.3



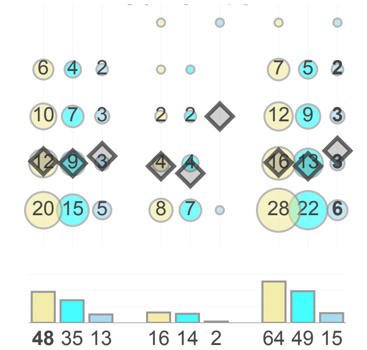
2.48(mean) Y1 emp-n-dk

	1st			2nd			both		
Ø	**2.48**	2.4	2.7	2.1	2.1	2.0	2.4	2.3	2.6
σ	**1.37**	1.3	1.5	1.0	1.0	1.4	1.3	1.2	1.5
σ²	**1.87**	1.7	2.4	1.0	1.0	2.0	1.7	1.5	2.3



2.04(mean) C1 emp-n-ao

	1st			2nd			both		
Ø	**2.04**	2.0	2.2	1.9	1.8	3.0	2.0	1.9	2.3
σ	**1.07**	1.1	1.1	1.2	1.0	2.8	1.1	1.0	1.3
σ²	**1.15**	1.1	1.3	1.5	1.0	8.0	1.2	1.1	1.8

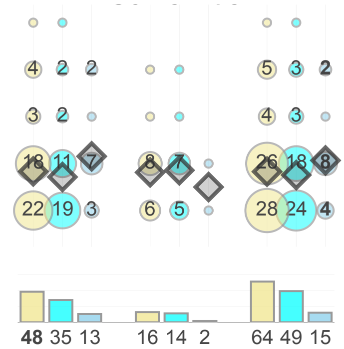


S1 - Expo 2010 France Pavilion (Shanghai)

(page 2/2)

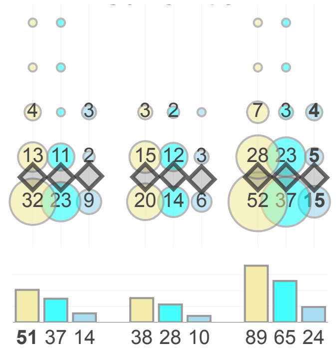
1.83(mean) G1 emp-n-su67

	1st			2nd			both		
Ø	**1.83**	1.7	2.2	1.8	1.9	1.5	1.8	1.8	2.1
σ	**1.02**	1.0	1.0	0.8	0.9	0.7	1.0	1.0	1.0
σ^2	**1.04**	1.0	1.0	0.7	0.7	0.5	0.9	0.9	0.9



1.55(mean) V1 emp-n-at67

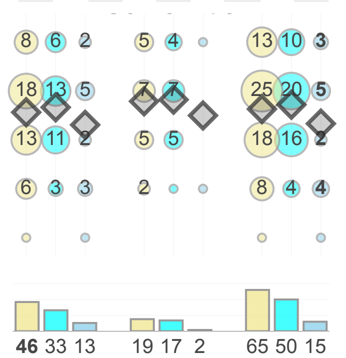
	1st			2nd			both		
Ø	**1.55**	1.5	1.6	1.6	1.6	1.5	1.6	1.6	1.5
σ	**0.88**	0.9	0.9	0.6	0.6	0.7	0.8	0.8	0.8
σ^2	**0.77**	0.8	0.7	0.4	0.4	0.5	0.6	0.6	0.6



S2 - Expo 2010 Finland Pavilion (Shanghai)

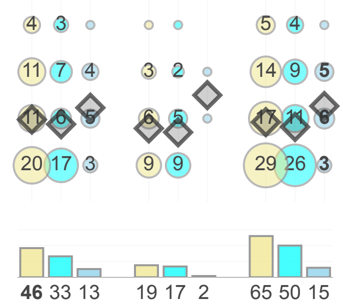
3.57(mean) X2 c-brewers

	1st			2nd			both		
Ø	**3.57**	3.7	3.3	3.8	3.8	3.5	3.6	3.7	3.3
σ	**1.00**	0.9	1.3	1.0	0.9	2.1	1.0	0.9	1.3
σ²	**1.01**	0.8	1.6	1.0	0.8	4.5	1.0	0.8	1.7



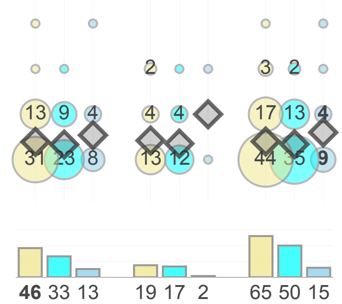
1.98(mean) G2 c-hyundai

	1st			2nd			both		
Ø	**1.98**	1.9	2.2	1.8	1.7	2.5	1.9	1.8	2.3
σ	**1.02**	1.1	0.9	0.9	0.9	0.7	1.0	1.0	0.9
σ²	**1.04**	1.1	0.9	0.8	0.8	0.5	1.0	1.0	0.8



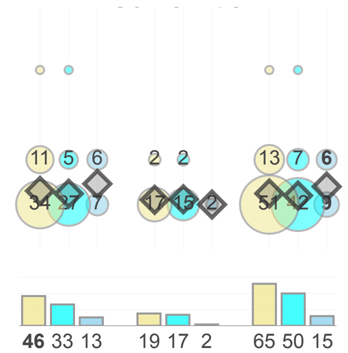
1.39(mean) B2 emp-n-uk

	1st			2nd			both		
Ø	**1.39**	1.3	1.5	1.4	1.4	2.0	1.4	1.3	1.6
σ	**0.65**	0.5	0.9	0.7	0.6	1.4	0.7	0.6	0.9
σ²	**0.42**	0.3	0.8	0.5	0.4	2.0	0.4	0.3	0.8



1.30(mean) U2 u-hamburg

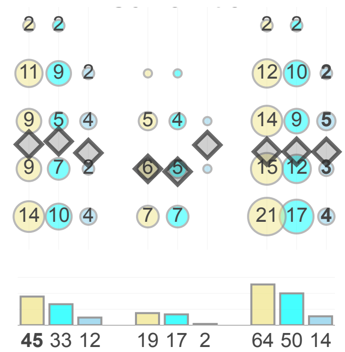
	1st			2nd			both		
Ø	**1.30**	1.2	1.5	1.1	1.1	1.0	1.2	1.2	1.4
σ	**0.59**	0.6	0.5	0.3	0.3	0.0	0.5	0.5	0.5
σ²	**0.35**	0.4	0.3	0.1	0.1	0.0	0.3	0.3	0.3



S3 - Expo 1967 Czechoslovakia Pavilion (Montreal)

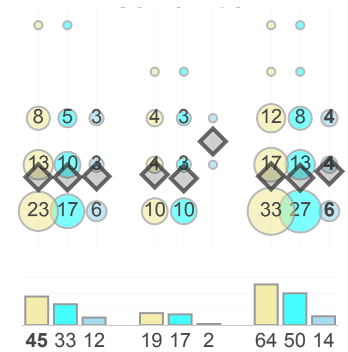
2.51(mean) H3 emp-n-au10

	1st			2nd			both		
Ø	**2.51**	2.6	2.3	2.0	1.9	2.5	2.4	2.4	2.4
σ	**1.29**	1.3	1.2	0.9	1.0	0.7	1.2	1.3	1.1
$σ^2$	**1.66**	1.8	1.3	0.9	0.9	0.5	1.5	1.6	1.2



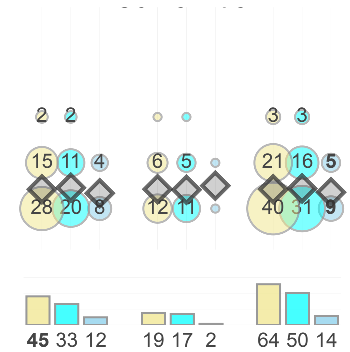
1.73(mean) V3 t-explorer

	1st			2nd			both		
Ø	**1.73**	1.7	1.8	1.8	1.7	2.5	1.8	1.7	1.9
σ	**0.91**	0.9	0.9	1.0	1.0	0.7	0.9	0.9	0.9
$σ^2$	**0.84**	0.9	0.8	1.0	1.0	0.5	0.9	0.9	0.7



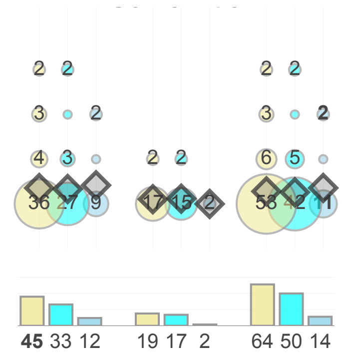
1.42(mean) B3 emp-n-ph

	1st			2nd			both		
Ø	**1.42**	1.5	1.3	1.4	1.4	1.5	1.4	1.4	1.4
σ	**0.58**	0.6	0.5	0.6	0.6	0.7	0.6	0.6	0.5
$σ^2$	**0.34**	0.4	0.2	0.4	0.4	0.5	0.3	0.4	0.2



1.36(mean) X3 emp-n-fr70

	1st			2nd			both		
Ø	**1.36**	1.3	1.4	1.1	1.1	1.0	1.3	1.3	1.4
σ	**0.80**	0.8	0.8	0.3	0.3	0.0	0.7	0.7	0.7
$σ^2$	**0.64**	0.7	0.6	0.1	0.1	0.0	0.5	0.5	0.6

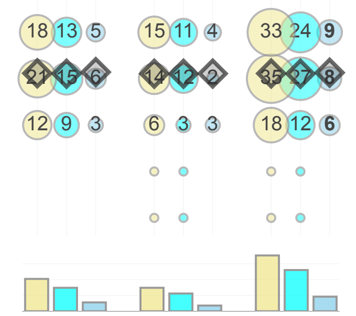


T1 - Expo 2012 Samsunung Corporate Pavilion (Yeosu)

(page 1/2)

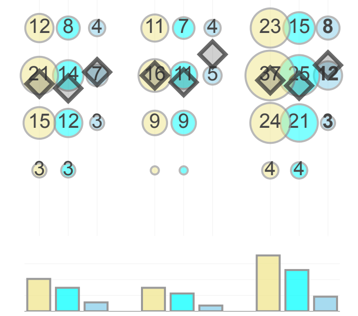
4.12(mean) T3 c-posco

	1st			2nd			both		
Ø	**4.12**	4.1	4.1	4.1	4.1	4.1	4.1	4.1	4.1
σ	**0.77**	0.8	0.8	1.0	1.0	0.9	0.9	0.9	0.8
σ²	**0.59**	0.6	0.6	0.9	1.0	0.9	0.7	0.8	0.7



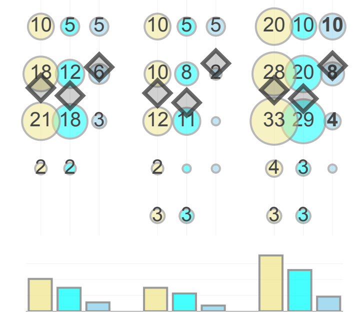
3.82(mean) S1 emp-n-fr10

	1st			2nd			both		
Ø	**3.82**	3.7	4.1	4.0	3.9	4.4	3.9	3.8	4.2
σ	**0.87**	0.9	0.7	0.8	0.8	0.5	0.8	0.9	0.7
σ²	**0.75**	0.8	0.5	0.7	0.7	0.3	0.7	0.8	0.5



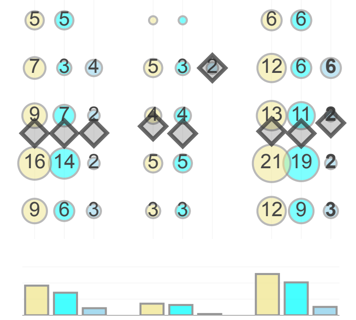
3.71(mean) T2 emp-c-oil

	1st			2nd			both		
Ø	**3.71**	3.5	4.1	3.6	3.4	4.2	3.7	3.5	4.2
σ	**0.83**	0.8	0.8	1.2	1.2	1.1	1.0	1.0	0.9
σ²	**0.69**	0.6	0.6	1.4	1.4	1.2	1.0	0.9	0.8



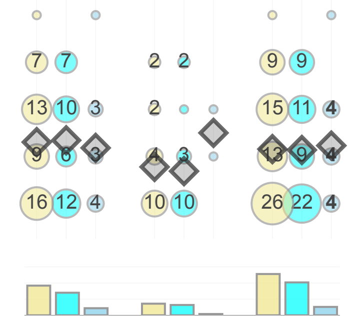
2.63(mean) H1 emp-n-cl

	1st			2nd			both		
Ø	**2.63**	2.6	2.6	2.8	2.6	4.0	2.7	2.6	2.8
σ	**1.27**	1.3	1.3	1.2	1.2	0.0	1.2	1.2	1.3
σ²	**1.62**	1.7	1.7	1.5	1.5	0.0	1.6	1.6	1.6



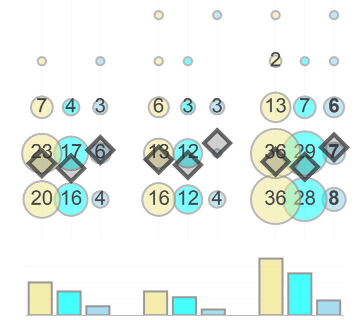
2.30(mean) V1 emp-n-at67

	1st			2nd			both		
Ø	**2.30**	2.3	2.2	1.8	1.7	2.5	2.2	2.1	2.2
σ	**1.17**	1.2	1.3	1.1	1.1	0.7	1.2	1.2	1.2
σ²	**1.37**	1.3	1.6	1.1	1.2	0.5	1.3	1.4	1.4



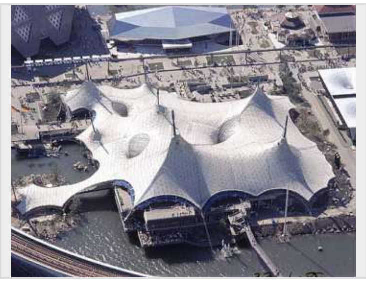
1.78(mean) U1 emp-n-nl67

	1st			2nd			both		
Ø	**1.78**	1.7	2.1	1.9	1.8	2.2	1.8	1.7	2.1
σ	**0.76**	0.7	0.9	1.0	0.8	1.4	0.9	0.7	1.1
σ²	**0.57**	0.4	0.8	1.0	0.6	1.9	0.7	0.5	1.2



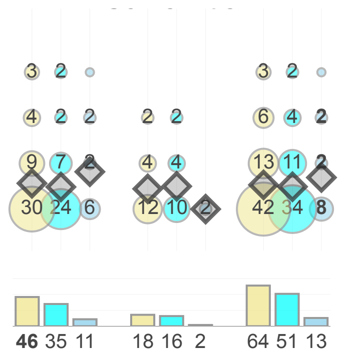
T1 - Expo 2012 Samsunung Corporate Pavilion (Yeosu)

(page 2/2)



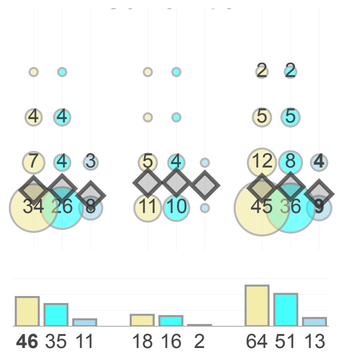
1.57(mean) Z1 emp-n-de67

	1st			2nd			both		
Ø	**1.57**	1.5	1.8	1.4	1.5	1.0	1.5	1.5	1.7
σ	**0.91**	0.9	1.1	0.7	0.7	0.0	0.9	0.8	1.0
σ^2	**0.83**	0.7	1.2	0.5	0.5	0.0	0.7	0.7	1.1



1.39(mean) D1 emp-r-ont

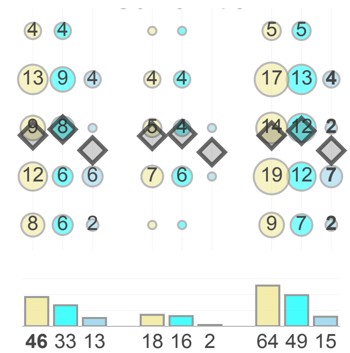
	1st			2nd			both		
Ø	**1.39**	1.4	1.3	1.6	1.6	1.5	1.4	1.5	1.3
σ	**0.74**	0.8	0.5	0.9	0.9	0.7	0.8	0.8	0.5
σ^2	**0.55**	0.7	0.2	0.7	0.8	0.5	0.6	0.7	0.2



T2 - Expo 2010 Oil Corporate Pavilion (Shanghai)

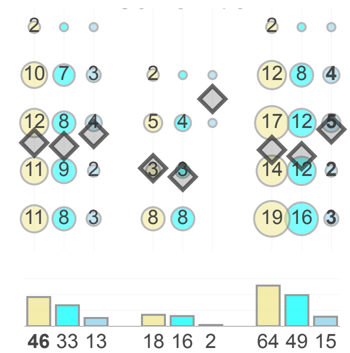
2.85(mean) A2 emp-n-de10

	1st			2nd			both		
Ø	**2.85**	3.0	2.5	2.8	2.9	2.5	2.8	2.9	2.5
σ	**1.26**	1.3	1.1	1.0	1.1	0.7	1.2	1.2	1.1
σ²	**1.60**	1.7	1.3	1.1	1.2	0.5	1.4	1.5	1.1



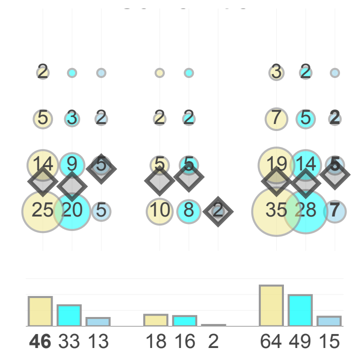
2.59(mean) H2 emp-c-info

	1st			2nd			both		
Ø	**2.59**	2.5	2.8	2.1	1.9	3.5	2.4	2.3	2.9
σ	**1.20**	1.2	1.3	1.1	1.0	0.7	1.2	1.2	1.2
σ²	**1.45**	1.4	1.7	1.2	1.1	0.5	1.4	1.3	1.6



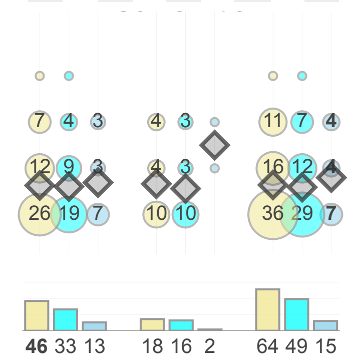
1.65(mean) V2 emp-n-it70

	1st			2nd			both		
Ø	**1.65**	1.5	1.9	1.7	1.8	1.0	1.7	1.6	1.8
σ	**0.85**	0.8	1.0	0.9	0.9	0.0	0.9	0.8	0.9
σ²	**0.72**	0.6	0.9	0.8	0.9	0.0	0.7	0.7	0.9

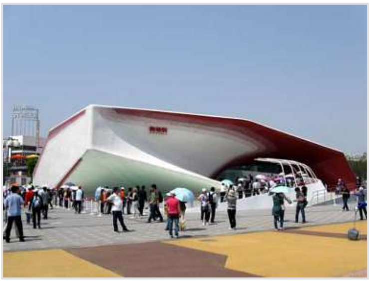


1.63(mean) W2 emp-n-sg

	1st			2nd			both		
Ø	**1.63**	1.6	1.7	1.7	1.6	2.5	1.6	1.6	1.8
σ	**0.83**	0.8	0.9	0.8	0.8	0.7	0.8	0.8	0.9
σ²	**0.68**	0.7	0.7	0.7	0.7	0.5	0.7	0.7	0.7

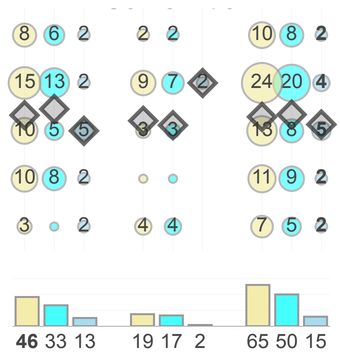


T3 - Expo 2012 Posco Corporate Pavilion (Yeosu)



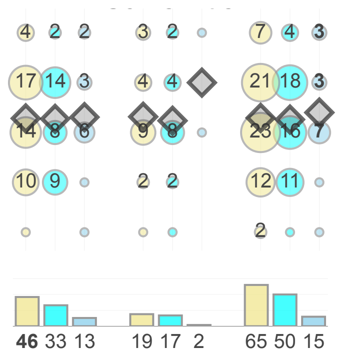
3.33(mean) Y3 emp-n-at10

	1st			2nd			both		
Ø	**3.33**	3.5	3.0	3.2	3.1	4.0	3.3	3.3	3.1
σ	**1.19**	1.1	1.3	1.4	1.4	0.0	1.2	1.2	1.2
σ²	**1.42**	1.3	1.7	1.8	2.0	0.0	1.5	1.5	1.6



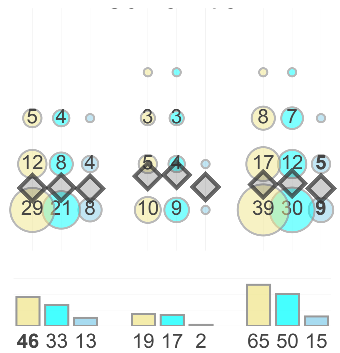
3.28(mean) S3 emp-n-cz

	1st			2nd			both		
Ø	**3.28**	3.3	3.3	3.3	3.2	4.0	3.3	3.3	3.4
σ	**0.98**	0.9	1.1	1.1	1.0	1.4	1.0	1.0	1.1
σ²	**0.96**	0.9	1.2	1.1	1.1	2.0	1.0	0.9	1.3



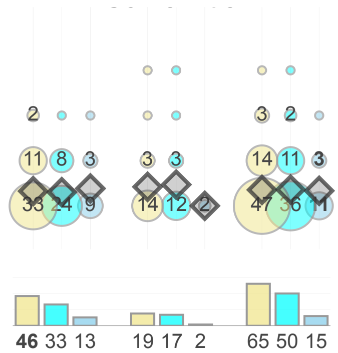
1.48(mean) E3 c-chemical

	1st			2nd			both		
Ø	**1.48**	1.5	1.5	1.7	1.8	1.5	1.6	1.6	1.5
σ	**0.69**	0.7	0.7	0.9	1.0	0.7	0.8	0.8	0.6
σ²	**0.48**	0.5	0.4	0.9	0.9	0.5	0.6	0.7	0.4



1.33(mean) C3 emp-n-fr67

	1st			2nd			both		
Ø	**1.33**	1.3	1.4	1.4	1.5	1.0	1.4	1.4	1.3
σ	**0.56**	0.5	0.7	0.8	0.9	0.0	0.6	0.7	0.6
σ²	**0.31**	0.3	0.4	0.7	0.8	0.0	0.4	0.4	0.4

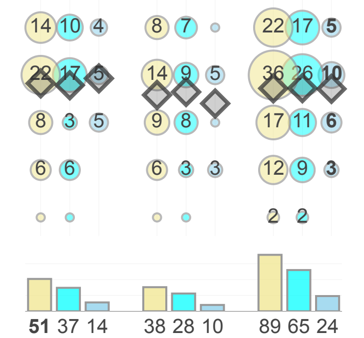


U1 - Expo 1967 Netherlands Pavilion (Montreal)

(page 1/2)

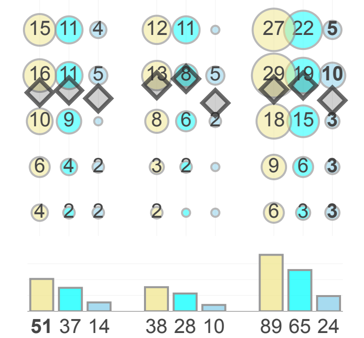
3.82(mean) U2 u-hamburg

	1st			2nd			both		
Ø	**3.82**	3.8	3.9	3.6	3.6	3.4	3.7	3.7	3.7
σ	**1.03**	1.1	0.8	1.1	1.1	1.1	1.1	1.1	1.0
$σ^2$	**1.07**	1.2	0.7	1.2	1.2	1.2	1.1	1.2	0.9



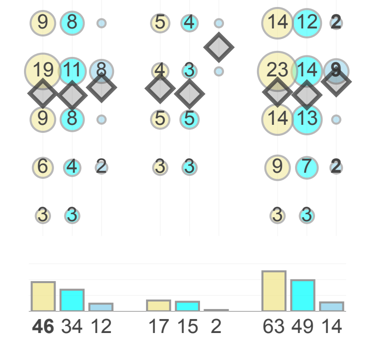
3.63(mean) U3 emp-n-nl70

	1st			2nd			both		
Ø	**3.63**	3.7	3.5	3.8	3.9	3.4	3.7	3.8	3.5
σ	**1.25**	1.2	1.5	1.1	1.1	1.2	1.2	1.2	1.3
$σ^2$	**1.56**	1.4	2.1	1.3	1.3	1.4	1.4	1.3	1.7



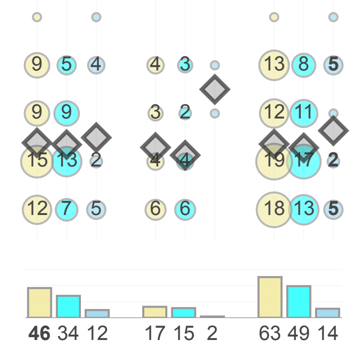
3.54(mean) S1 emp-n-fr10

	1st			2nd			both		
Ø	**3.54**	3.5	3.7	3.6	3.5	4.5	3.6	3.5	3.8
σ	**1.15**	1.2	0.9	1.1	1.1	0.7	1.1	1.2	0.9
$σ^2$	**1.32**	1.5	0.8	1.2	1.3	0.5	1.3	1.4	0.8



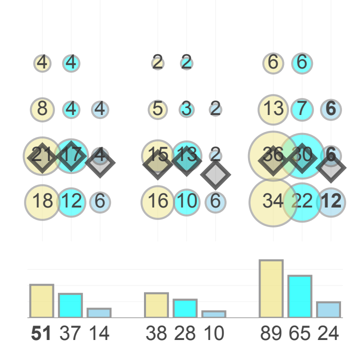
2.39(mean) A1 emp-n-ca10

	1st			2nd			both		
Ø	**2.39**	2.4	2.5	2.3	2.1	3.5	2.4	2.3	2.6
σ	**1.14**	1.0	1.6	1.2	1.2	0.7	1.2	1.0	1.5
$σ^2$	**1.31**	1.0	2.5	1.5	1.4	0.5	1.3	1.1	2.2



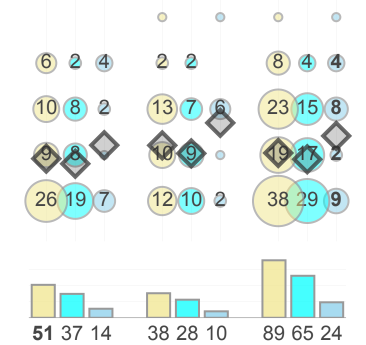
1.96(mean) V1 emp-n-at67

	1st			2nd			both		
Ø	**1.96**	2.0	1.9	1.8	1.9	1.6	1.9	2.0	1.8
σ	**0.92**	0.9	0.9	0.9	0.9	0.8	0.9	0.9	0.8
$σ^2$	**0.84**	0.9	0.7	0.7	0.8	0.7	0.8	0.8	0.7



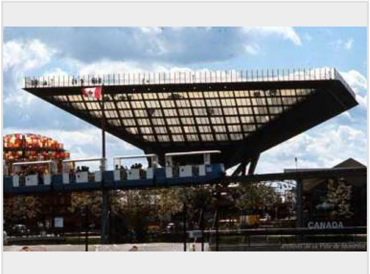
1.92(mean) T1 c-samsung

	1st			2nd			both		
Ø	**1.92**	1.8	2.2	2.2	2.0	2.7	2.0	1.9	2.4
σ	**1.09**	1.0	1.4	1.0	1.0	1.2	1.1	1.0	1.3
$σ^2$	**1.19**	0.9	1.9	1.1	0.9	1.3	1.2	0.9	1.6



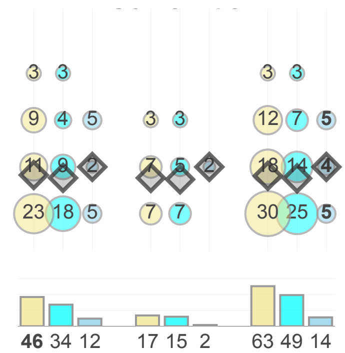
U1 - Expo 1967 Netherlands Pavilion (Montreal)

(page 2/2)



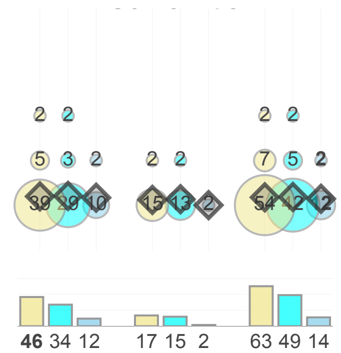
1.83(mean) E1 host-ca

	1st			2nd			both		
Ø	**1.83**	1.8	2.0	1.8	1.7	2.0	1.8	1.8	2.0
σ	**0.97**	1.0	1.0	0.8	0.8	0.0	0.9	0.9	0.9
σ^2	**0.95**	1.0	0.9	0.6	0.6	0.0	0.8	0.9	0.8



1.20(mean) W1 host-culture

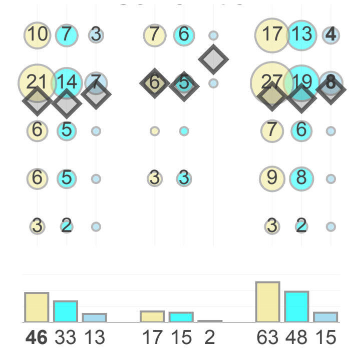
	1st			2nd			both		
Ø	**1.20**	1.2	1.2	1.1	1.1	1.0	1.2	1.2	1.1
σ	**0.50**	0.5	0.4	0.3	0.4	0.0	0.5	0.5	0.4
σ^2	**0.25**	0.3	0.2	0.1	0.1	0.0	0.2	0.2	0.1



U2 - Expo 2010 Hamburg Urban Pavilion (Shanghai)

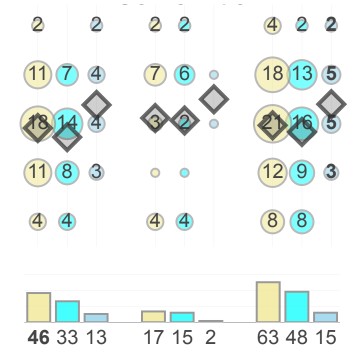
3.63(mean) C2 emp-n-dz

	1st			2nd			both		
Ø	**3.63**	3.6	3.8	4.0	3.9	4.5	3.7	3.7	3.9
σ	**1.16**	1.2	1.2	1.1	1.2	0.7	1.2	1.2	1.1
σ²	**1.35**	1.4	1.4	1.3	1.4	0.5	1.3	1.4	1.3



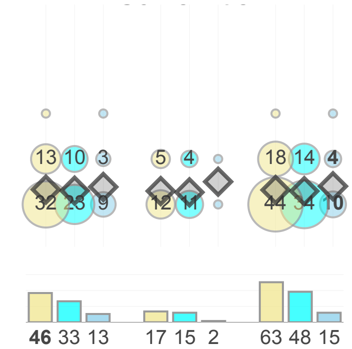
2.91(mean) T2 emp-c-oil

	1st			2nd			both		
Ø	**2.91**	2.7	3.4	3.1	3.1	3.5	3.0	2.8	3.4
σ	**1.01**	0.9	1.0	1.4	1.5	0.7	1.1	1.1	1.0
σ²	**1.01**	0.9	1.1	2.0	2.2	0.5	1.3	1.3	1.0



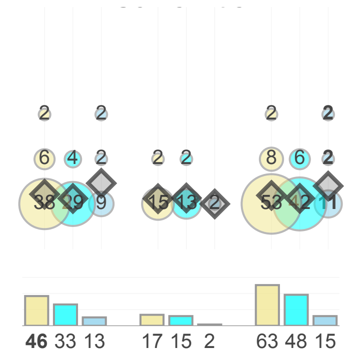
1.33(mean) Y2 emp-c-gm

	1st			2nd			both		
Ø	**1.33**	1.3	1.4	1.3	1.3	1.5	1.3	1.3	1.4
σ	**0.52**	0.5	0.7	0.5	0.5	0.7	0.5	0.5	0.6
σ²	**0.27**	0.2	0.4	0.2	0.2	0.5	0.3	0.2	0.4



1.22(mean) F2 emp-n-jp10

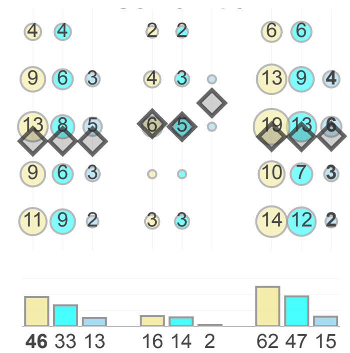
	1st			2nd			both		
Ø	**1.22**	1.1	1.5	1.1	1.1	1.0	1.2	1.1	1.4
σ	**0.51**	0.3	0.8	0.3	0.4	0.0	0.5	0.3	0.7
σ²	**0.26**	0.1	0.6	0.1	0.1	0.0	0.2	0.1	0.5



U3 - Expo 1970 Netherlands Pavilion (Osaka)

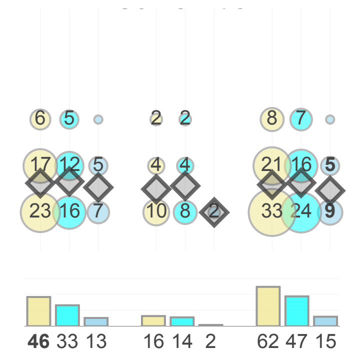
2.70(mean) T3 c-posco

	1st			2nd			both		
Ø	**2.70**	2.7	2.7	3.1	3.0	3.5	2.8	2.8	2.8
σ	**1.28**	1.4	1.0	1.3	1.4	0.7	1.3	1.4	1.0
σ²	**1.64**	1.9	1.1	1.7	1.8	0.5	1.6	1.9	1.0



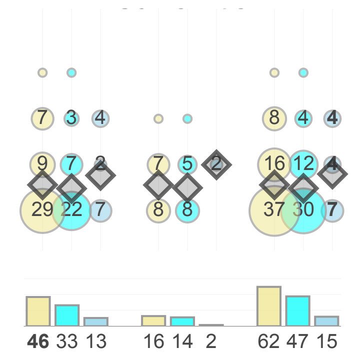
1.63(mean) D3 emp-c-pulp

	1st			2nd			both		
Ø	**1.63**	1.7	1.5	1.5	1.6	1.0	1.6	1.6	1.5
σ	**0.71**	0.7	0.7	0.7	0.8	0.0	0.7	0.7	0.6
σ²	**0.50**	0.5	0.4	0.5	0.6	0.0	0.5	0.5	0.4



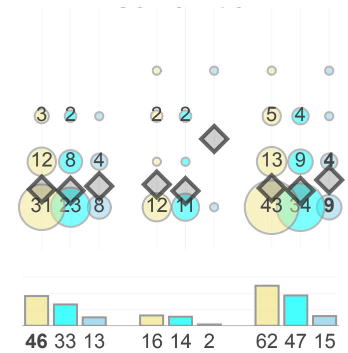
1.57(mean) Z3 emp-c-tele

	1st			2nd			both		
Ø	**1.57**	1.5	1.8	1.6	1.5	2.0	1.6	1.5	1.8
σ	**0.83**	0.8	0.9	0.6	0.7	0.0	0.8	0.7	0.9
σ²	**0.70**	0.6	0.9	0.4	0.4	0.0	0.6	0.6	0.7



1.39(mean) F3 emp-n-jp00

	1st			2nd			both		
Ø	**1.39**	1.4	1.5	1.5	1.4	2.5	1.4	1.4	1.6
σ	**0.61**	0.6	0.7	1.0	0.7	2.1	0.7	0.6	0.9
σ²	**0.38**	0.4	0.4	0.9	0.6	4.5	0.5	0.4	0.8

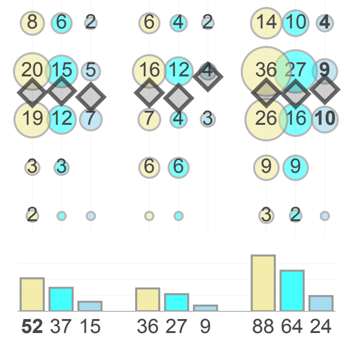


V1 - Expo 1967 Austria Pavilion (Montreal)

(page 1/2)

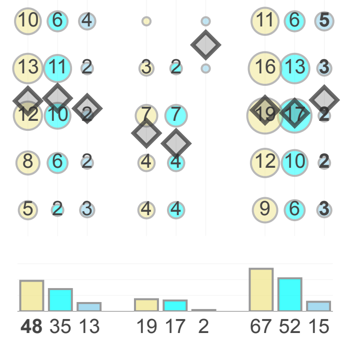
3.56(mean) V3 t-explorer

	1st			2nd			both		
Ø	**3.56**	3.6	3.5	3.6	3.4	3.9	3.6	3.5	3.6
σ	**0.96**	1.0	1.0	1.1	1.1	0.8	1.0	1.0	0.9
σ²	**0.92**	0.9	1.0	1.1	1.3	0.6	1.0	1.0	0.9



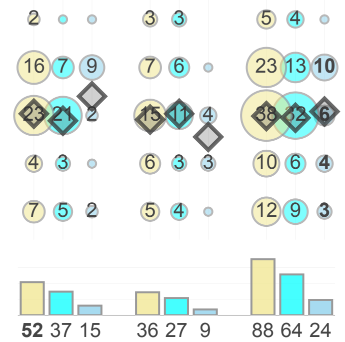
3.31(mean) X1 t-tours

	1st			2nd			both		
Ø	**3.31**	3.4	3.2	2.6	2.4	4.5	3.1	3.1	3.3
σ	**1.27**	1.1	1.6	1.2	1.0	0.7	1.3	1.2	1.6
σ²	**1.62**	1.3	2.6	1.4	1.0	0.5	1.6	1.4	2.5



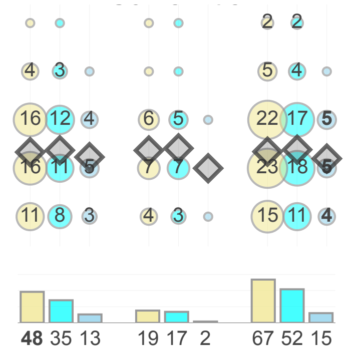
3.04(mean) V2 emp-n-it70

	1st			2nd			both		
Ø	**3.04**	2.9	3.4	2.9	3.0	2.6	3.0	3.0	3.1
σ	**1.05**	1.0	1.2	1.1	1.2	0.9	1.1	1.1	1.1
σ²	**1.10**	0.9	1.4	1.3	1.4	0.8	1.2	1.1	1.3



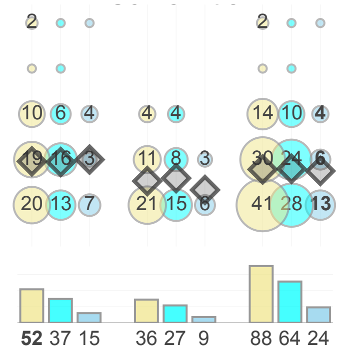
2.33(mean) B1 emp-n-su70

	1st			2nd			both		
Ø	**2.33**	2.4	2.2	2.4	2.4	2.0	2.3	2.4	2.2
σ	**1.00**	1.0	0.9	1.1	1.1	1.4	1.0	1.0	0.9
σ²	**0.99**	1.1	0.9	1.1	1.1	2.0	1.0	1.1	0.9



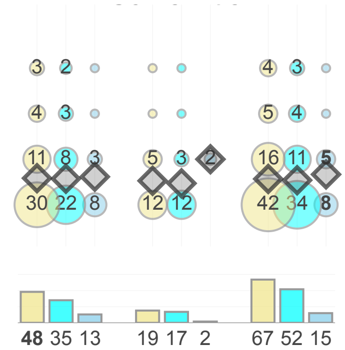
1.96(mean) U1 emp-n-nl67

	1st			2nd			both		
Ø	**1.96**	1.9	2.0	1.5	1.6	1.3	1.8	1.8	1.8
σ	**1.01**	0.9	1.2	0.7	0.7	0.5	0.9	0.9	1.0
σ²	**1.02**	0.9	1.4	0.5	0.6	0.3	0.8	0.8	1.1



1.58(mean) T1 c-samsung

	1st			2nd			both		
Ø	**1.58**	1.6	1.6	1.5	1.5	2.0	1.6	1.5	1.7
σ	**0.90**	0.9	1.0	0.8	0.9	0.0	0.9	0.9	0.9
σ²	**0.80**	0.8	0.9	0.7	0.8	0.0	0.8	0.8	0.8

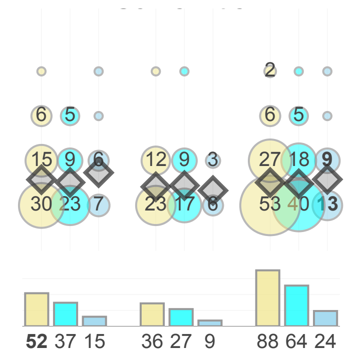


V1 - Expo 1967 Austria Pavilion (Montreal)

(page 2/2)

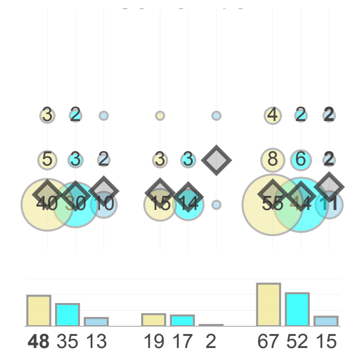
1.58(mean) S1 emp-n-fr10

	1st			2nd			both		
Ø	**1.58**	1.5	1.7	1.4	1.4	1.3	1.5	1.5	1.6
σ	**0.78**	0.7	0.9	0.6	0.7	0.5	0.7	0.7	0.8
σ^2	**0.60**	0.5	0.8	0.4	0.5	0.3	0.5	0.5	0.6



1.23(mean) F1 emp-c-fuji

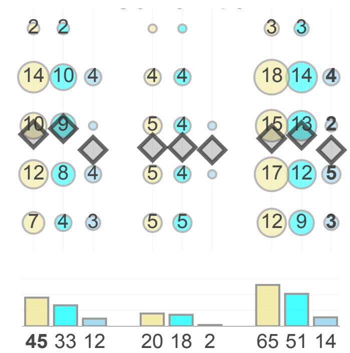
	1st			2nd			both		
Ø	**1.23**	1.2	1.3	1.3	1.2	2.0	1.2	1.2	1.4
σ	**0.56**	0.5	0.6	0.6	0.4	1.4	0.6	0.5	0.7
σ^2	**0.31**	0.3	0.4	0.3	0.2	2.0	0.3	0.2	0.5



V2 - Expo 1970 Italy Pavilion (Osaka)

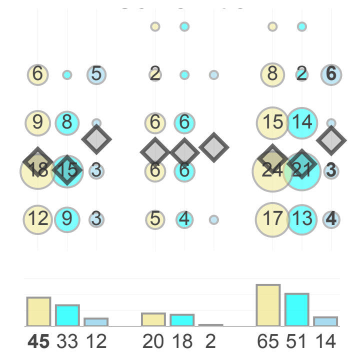
2.82(mean) D2 g-africa

	1st			2nd			both		
Ø	**2.82**	2.9	2.5	2.6	2.6	2.5	2.7	2.8	2.5
σ	**1.17**	1.1	1.2	1.2	1.3	0.7	1.2	1.2	1.2
σ²	**1.38**	1.3	1.5	1.5	1.7	0.5	1.4	1.4	1.3



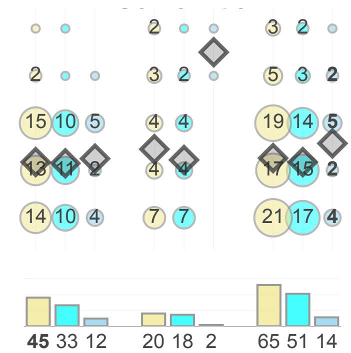
2.20(mean) E2 host-cn

	1st			2nd			both		
Ø	**2.20**	2.0	2.7	2.4	2.4	2.5	2.3	2.2	2.6
σ	**0.99**	0.8	1.3	1.1	1.1	2.1	1.0	0.9	1.3
σ²	**0.98**	0.7	1.7	1.3	1.2	4.5	1.1	0.9	1.8



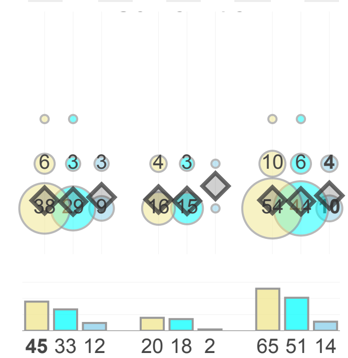
2.18(mean) Z2 emp-n-no

	1st			2nd			both		
Ø	**2.18**	2.2	2.3	2.5	2.2	4.5	2.3	2.2	2.6
σ	**1.01**	1.0	1.1	1.4	1.3	0.7	1.1	1.1	1.3
σ²	**1.01**	1.0	1.1	1.9	1.6	0.5	1.3	1.2	1.6

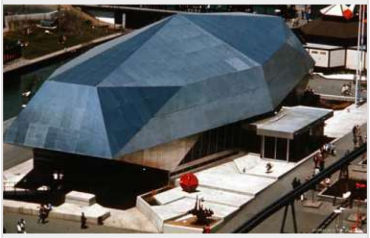


1.18(mean) S2 emp-n-fi

	1st			2nd			both		
Ø	**1.18**	1.2	1.3	1.2	1.2	1.5	1.2	1.2	1.3
σ	**0.44**	0.4	0.5	0.4	0.4	0.7	0.4	0.4	0.5
σ²	**0.19**	0.2	0.2	0.2	0.1	0.5	0.2	0.2	0.2

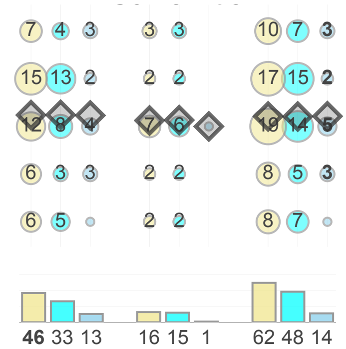


V3 - Expo 1967 Man The Explorer Theme Pav. (Montreal)



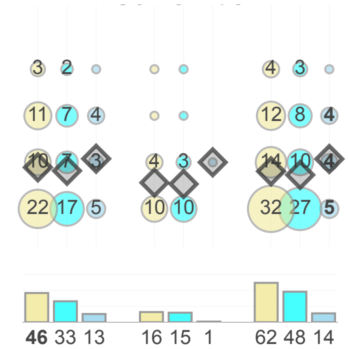
3.24(mean) A3 g-europe

	1st			2nd			both		
Ø	**3.24**	3.2	3.2	3.1	3.1	3.0	3.2	3.2	3.2
σ	**1.25**	1.3	1.3	1.3	1.3	0.0	1.2	1.3	1.3
σ²	**1.56**	1.6	1.7	1.6	1.7	0.0	1.5	1.6	1.6



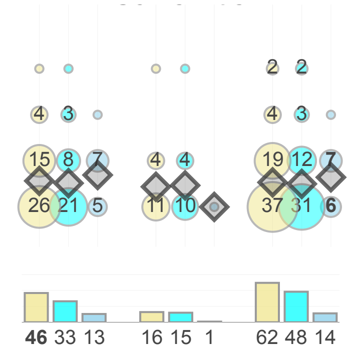
1.89(mean) U3 emp-n-nl70

	1st			2nd			both		
Ø	**1.89**	1.8	2.1	1.6	1.5	2.0	1.8	1.7	2.1
σ	**0.99**	1.0	1.0	0.9	0.9	0.0	1.0	1.0	1.0
σ²	**0.99**	1.0	1.1	0.8	0.8	0.0	0.9	0.9	1.0



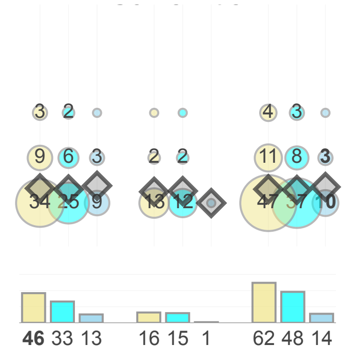
1.57(mean) G3 host-de

	1st			2nd			both		
Ø	**1.57**	1.5	1.7	1.4	1.5	1.0	1.5	1.5	1.6
σ	**0.75**	0.8	0.6	0.8	0.8	0.0	0.8	0.8	0.6
σ²	**0.56**	0.6	0.4	0.7	0.7	0.0	0.6	0.6	0.4



1.33(mean) W3 t-future

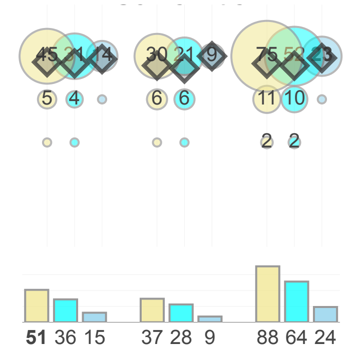
	1st			2nd			both		
Ø	**1.33**	1.3	1.4	1.3	1.3	1.0	1.3	1.3	1.4
σ	**0.60**	0.6	0.7	0.6	0.6	0.0	0.6	0.6	0.6
σ²	**0.36**	0.3	0.4	0.3	0.4	0.0	0.3	0.3	0.4



W1 - Expo 2010 Expo Culture Center Host Pav. (Shanghai) (page 1/2)

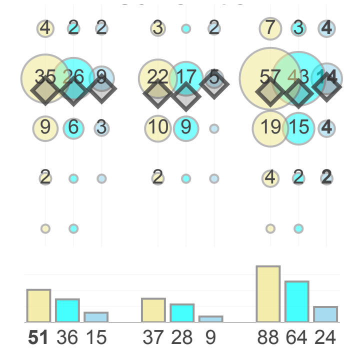
4.86(mean) W3 t-future

	1st			2nd			both		
Ø	**4.86**	4.8	4.9	4.8	4.7	5.0	4.8	4.8	5.0
σ	**0.40**	0.4	0.3	0.5	0.5	0.0	0.4	0.5	0.2
σ²	**0.16**	0.2	0.1	0.2	0.3	0.0	0.2	0.2	0.0



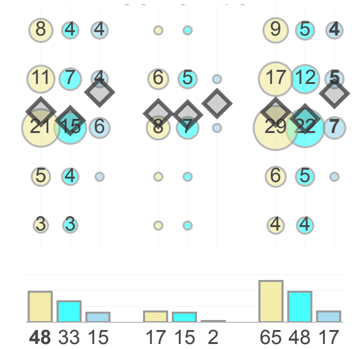
3.76(mean) W2 emp-n-sg

	1st			2nd			both		
Ø	**3.76**	3.8	3.8	3.7	3.6	3.9	3.7	3.7	3.8
σ	**0.74**	0.7	0.8	0.7	0.6	0.9	0.7	0.7	0.8
σ²	**0.54**	0.5	0.6	0.5	0.4	0.9	0.5	0.5	0.7



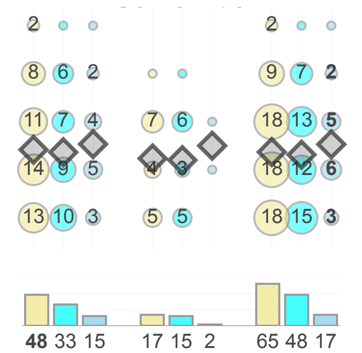
3.33(mean) Y1 emp-n-dk

	1st			2nd			both		
Ø	**3.33**	3.2	3.7	3.3	3.3	3.5	3.3	3.2	3.7
σ	**1.08**	1.1	1.0	0.9	1.0	0.7	1.0	1.0	0.9
σ²	**1.16**	1.2	0.9	0.8	0.9	0.5	1.1	1.1	0.8



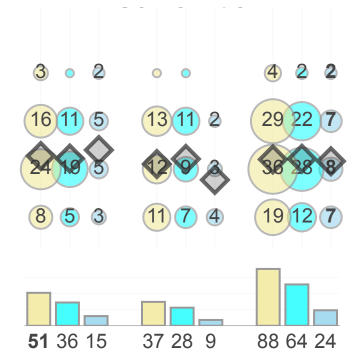
2.42(mean) T1 c-samsung

	1st			2nd			both		
Ø	**2.42**	2.4	2.5	2.2	2.2	2.5	2.4	2.3	2.5
σ	**1.18**	1.2	1.2	1.0	1.0	0.7	1.1	1.1	1.1
σ²	**1.40**	1.4	1.4	0.9	1.0	0.5	1.3	1.3	1.3



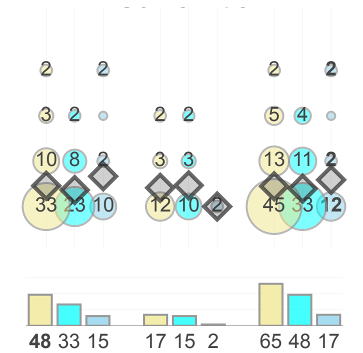
2.27(mean) X1 t-tours

	1st			2nd			both		
Ø	**2.27**	2.2	2.4	2.1	2.2	1.8	2.2	2.2	2.2
σ	**0.80**	0.7	1.0	0.9	0.9	0.8	0.8	0.8	1.0
σ²	**0.64**	0.5	1.0	0.8	0.8	0.7	0.7	0.6	0.9



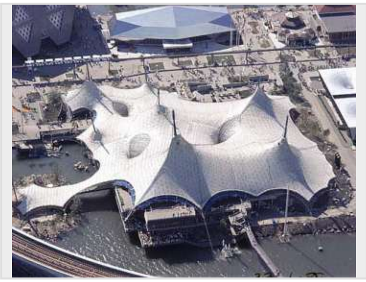
1.46(mean) F1 emp-c-fuji

	1st			2nd			both		
Ø	**1.46**	1.4	1.7	1.4	1.5	1.0	1.4	1.4	1.6
σ	**0.80**	0.6	1.1	0.7	0.7	0.0	0.8	0.6	1.1
σ²	**0.64**	0.4	1.2	0.5	0.6	0.0	0.6	0.4	1.1



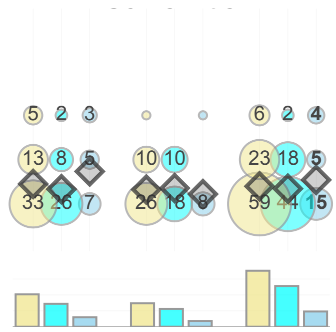
W1 - Expo 2010 Expo Culture Center Host Pav. (Shanghai)

(page 2/2)



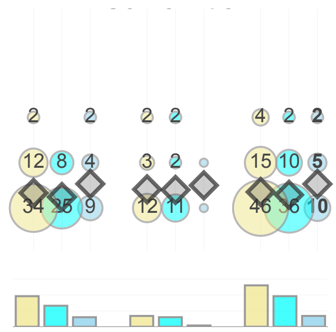
1.45(mean) Z1 emp-n-de67

	1st			2nd			both		
Ø	**1.45**	1.3	1.7	1.3	1.4	1.2	1.4	1.3	1.5
σ	**0.67**	0.6	0.8	0.5	0.5	0.7	0.6	0.5	0.8
σ^2	**0.45**	0.3	0.6	0.3	0.2	0.4	0.4	0.3	0.6



1.33(mean) C1 emp-n-ao

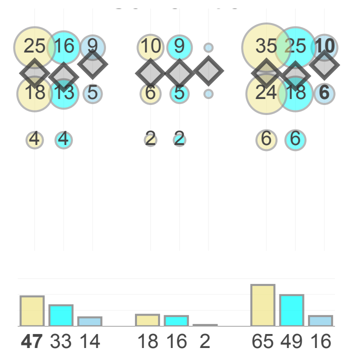
	1st			2nd			both		
Ø	**1.33**	1.2	1.5	1.4	1.4	1.5	1.4	1.3	1.5
σ	**0.56**	0.4	0.7	0.7	0.7	0.7	0.6	0.5	0.7
σ^2	**0.31**	0.2	0.6	0.5	0.5	0.5	0.4	0.3	0.5



W2 - Expo 2010 Singapore Pavilion (Shanghai)

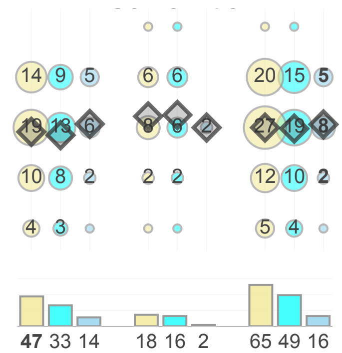
4.45(mean) Y2 emp-c-gm

	1st			2nd			both		
Ø	**4.45**	4.4	4.6	4.4	4.4	4.5	4.4	4.4	4.6
σ	**0.65**	0.7	0.5	0.7	0.7	0.7	0.7	0.7	0.5
σ²	**0.43**	0.5	0.2	0.5	0.5	0.5	0.4	0.5	0.3



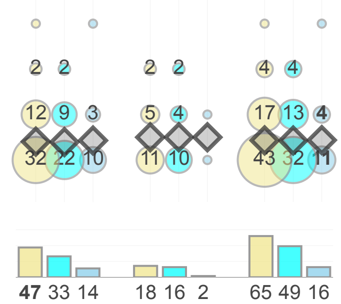
2.91(mean) H2 emp-c-info

	1st			2nd			both		
Ø	**2.91**	2.8	3.1	3.2	3.3	3.0	3.0	3.0	3.1
σ	**0.93**	0.9	0.9	0.9	1.0	0.0	0.9	1.0	0.9
σ²	**0.86**	0.9	0.8	0.9	1.0	0.0	0.9	0.9	0.7



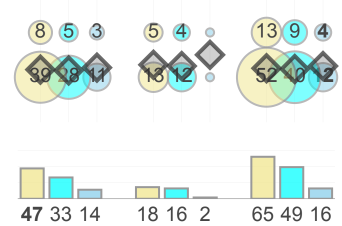
1.40(mean) V2 emp-n-it70

	1st			2nd			both		
Ø	**1.40**	1.4	1.4	1.5	1.5	1.5	1.4	1.4	1.4
σ	**0.68**	0.6	0.9	0.7	0.7	0.7	0.7	0.6	0.8
σ²	**0.46**	0.4	0.7	0.5	0.5	0.5	0.5	0.4	0.7



1.17(mean) C2 emp-n-dz

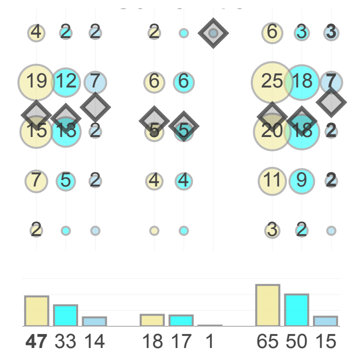
	1st			2nd			both		
Ø	**1.17**	1.2	1.2	1.3	1.3	1.5	1.2	1.2	1.3
σ	**0.38**	0.4	0.4	0.5	0.4	0.7	0.4	0.4	0.4
σ²	**0.14**	0.1	0.2	0.2	0.2	0.5	0.2	0.2	0.2

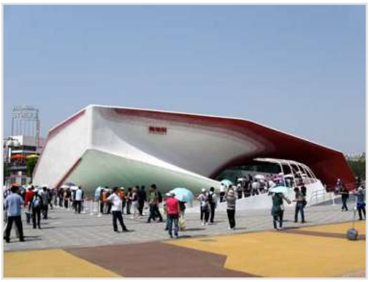


W3 - Expo 1998 Pav. of the Future Theme Pavilion (Lisboa)

3.34(mean) C3 emp-n-fr67

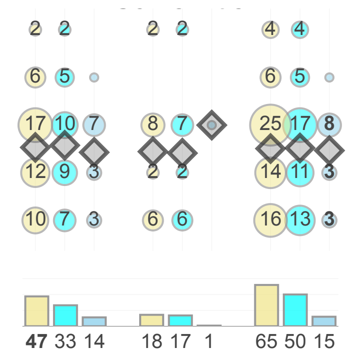
	1st			2nd			both		
Ø	**3.34**	3.3	3.5	3.2	3.1	5.0	3.3	3.2	3.6
σ	**0.98**	0.9	1.2	1.1	1.1	0.0	1.0	1.0	1.2
σ²	**0.97**	0.8	1.3	1.2	1.1	0.0	1.0	0.9	1.4





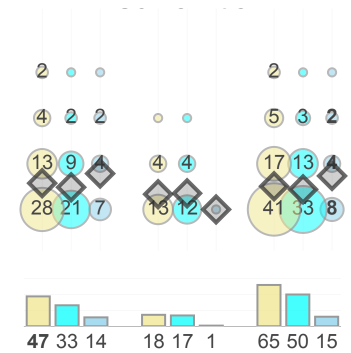
2.53(mean) Y3 emp-n-at10

	1st			2nd			both		
Ø	**2.53**	2.6	2.4	2.4	2.4	3.0	2.5	2.5	2.5
σ	**1.10**	1.2	0.9	1.3	1.3	0.0	1.1	1.2	0.9
σ²	**1.21**	1.4	0.9	1.7	1.8	0.0	1.3	1.5	0.8



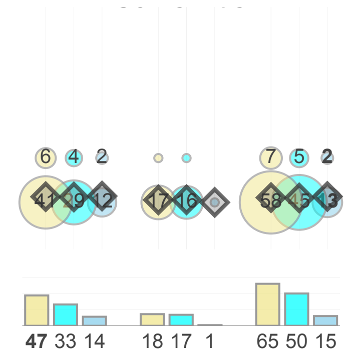
1.57(mean) G3 host-de

	1st			2nd			both		
Ø	**1.57**	1.5	1.8	1.3	1.4	1.0	1.5	1.4	1.7
σ	**0.83**	0.8	1.0	0.6	0.6	0.0	0.8	0.7	1.0
σ²	**0.68**	0.6	1.0	0.4	0.4	0.0	0.6	0.5	0.9



1.13(mean) U3 emp-n-nl70

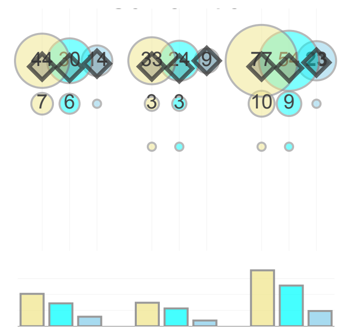
	1st			2nd			both		
Ø	**1.13**	1.1	1.1	1.1	1.1	1.0	1.1	1.1	1.1
σ	**0.34**	0.3	0.4	0.2	0.2	0.0	0.3	0.3	0.4
σ²	**0.11**	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1



X1 - Expo 2010 Innovative Tours Theme Pavilion (Shanghai) (page 1/2)

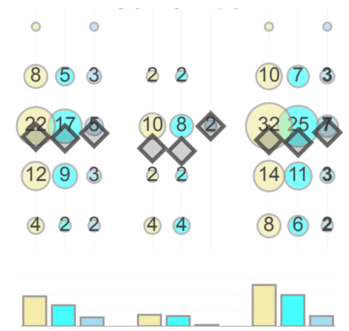
4.86(mean) X3 emp-n-fr70

	1st			2nd			both		
Ø	**4.86**	4.8	4.9	4.9	4.8	5.0	4.9	4.8	5.0
σ	**0.35**	0.4	0.3	0.4	0.5	0.0	0.4	0.4	0.2
σ²	**0.12**	0.1	0.1	0.2	0.2	0.0	0.1	0.2	0.0



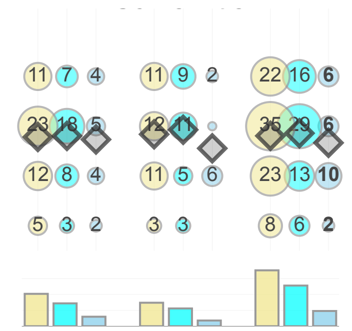
2.79(mean) D1 emp-r-ont

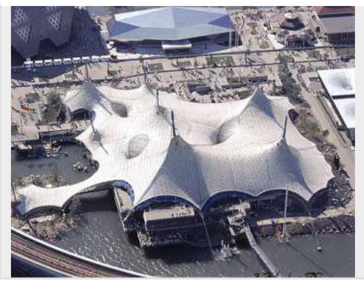
	1st			2nd			both		
Ø	**2.79**	2.8	2.9	2.6	2.5	3.0	2.7	2.7	2.9
σ	**0.91**	0.8	1.2	1.0	1.0	0.0	0.9	0.9	1.1
σ²	**0.82**	0.6	1.4	1.0	1.1	0.0	0.9	0.8	1.2



2.78(mean) X2 c-brewers

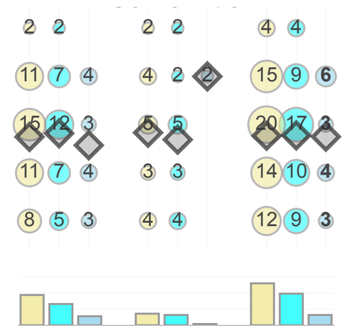
	1st			2nd			both		
Ø	**2.78**	2.8	2.7	2.8	2.9	2.6	2.8	2.9	2.7
σ	**0.90**	0.9	1.0	1.0	1.0	0.9	0.9	0.9	1.0
σ²	**0.81**	0.7	1.1	0.9	1.0	0.8	0.8	0.8	0.9





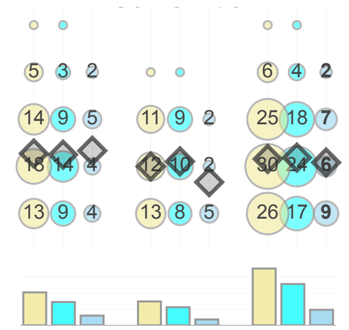
2.74(mean) Z1 emp-n-de67

	1st			2nd			both		
Ø	**2.74**	2.8	2.6	2.8	2.7	4.0	2.8	2.8	2.8
σ	**1.13**	1.1	1.2	1.3	1.4	0.0	1.2	1.2	1.2
σ²	**1.28**	1.3	1.3	1.8	1.8	0.0	1.4	1.4	1.4



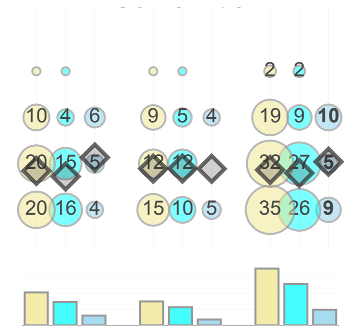
2.27(mean) W1 host-culture

	1st			2nd			both		
Ø	**2.27**	2.3	2.3	2.0	2.1	1.7	2.2	2.2	2.1
σ	**1.02**	1.0	1.0	0.9	0.9	0.9	1.0	1.0	1.0
σ²	**1.04**	1.1	1.1	0.8	0.8	0.8	0.9	0.9	1.0



1.84(mean) Y1 emp-n-dk

	1st			2nd			both		
Ø	**1.84**	1.7	2.1	1.9	1.9	1.9	1.9	1.8	2.0
σ	**0.81**	0.8	0.8	0.9	0.8	1.1	0.8	0.8	0.9
σ²	**0.65**	0.6	0.7	0.8	0.7	1.1	0.7	0.6	0.8

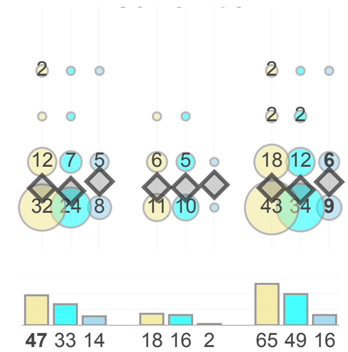


X1 - Expo 2010 Innovative Tours Theme Pavilion (Shanghai)

(page 2/2)

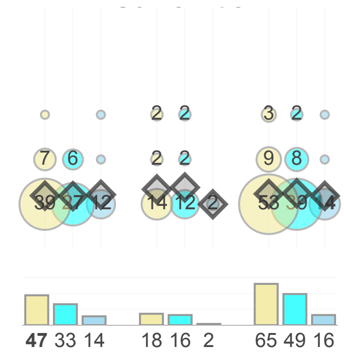
1.43(mean) S1 emp-n-fr10

	1st			2nd			both		
Ø	**1.43**	1.4	1.6	1.4	1.4	1.5	1.4	1.4	1.6
σ	**0.74**	0.7	0.9	0.6	0.6	0.7	0.7	0.7	0.8
$σ^2$	**0.55**	0.5	0.7	0.4	0.4	0.5	0.5	0.5	0.7



1.19(mean) E1 host-ca

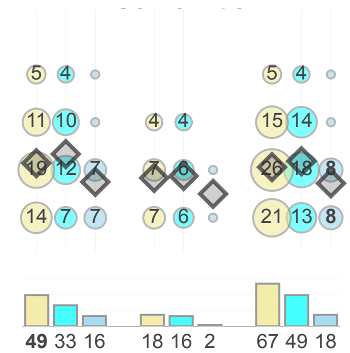
	1st			2nd			both		
Ø	**1.19**	1.2	1.2	1.3	1.4	1.0	1.2	1.2	1.2
σ	**0.45**	0.4	0.6	0.7	0.7	0.0	0.5	0.5	0.5
$σ^2$	**0.20**	0.2	0.3	0.5	0.5	0.0	0.3	0.3	0.3



X2 - Expo 1967 Brewers Pavilion (Montreal)

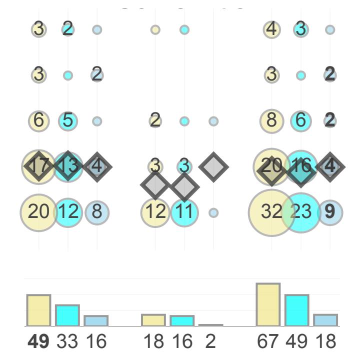
2.14(mean) D2 g-africa

		1st			2nd			both		
Ø	**2.14**	2.3	1.8	1.8	1.9	1.5	2.1	2.2	1.7
σ	**0.96**	1.0	0.9	0.8	0.8	0.7	0.9	0.9	0.8
σ²	**0.92**	0.9	0.7	0.6	0.7	0.5	0.8	0.9	0.7



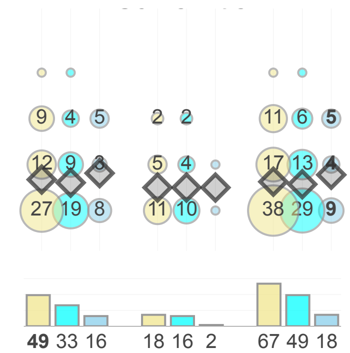
2.02(mean) Z2 emp-n-no

		1st			2nd			both		
Ø	**2.02**	2.0	2.0	1.6	1.6	2.0	1.9	1.9	2.0
σ	**1.16**	1.1	1.3	1.1	1.1	1.4	1.2	1.1	1.3
σ²	**1.35**	1.2	1.7	1.2	1.2	2.0	1.3	1.2	1.6



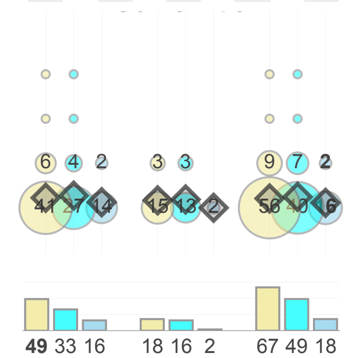
1.67(mean) G2 c-hyundai

		1st			2nd			both		
Ø	**1.67**	1.6	1.8	1.5	1.5	1.5	1.6	1.6	1.8
σ	**0.85**	0.8	0.9	0.7	0.7	0.7	0.8	0.8	0.9
σ²	**0.72**	0.7	0.8	0.5	0.5	0.5	0.7	0.6	0.8



1.22(mean) U2 u-hamburg

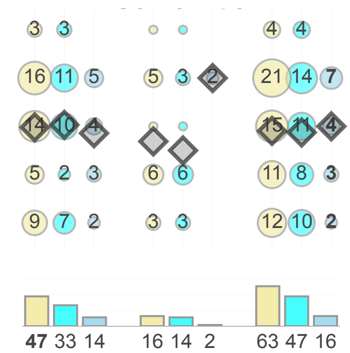
		1st			2nd			both		
Ø	**1.22**	1.3	1.1	1.2	1.2	1.0	1.2	1.2	1.1
σ	**0.59**	0.7	0.3	0.4	0.4	0.0	0.5	0.6	0.3
σ²	**0.34**	0.5	0.1	0.1	0.2	0.0	0.3	0.4	0.1



X3 - Expo 1970 France Pavilion (Osaka)

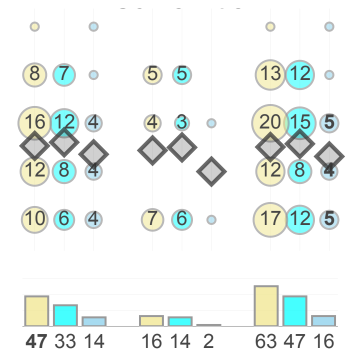
2.98(mean) V3 t-explorer

	1st			2nd			both		
Ø	**2.98**	3.0	2.9	2.7	2.5	4.0	2.9	2.9	3.0
σ	**1.22**	1.3	1.1	1.3	1.3	0.0	1.2	1.3	1.1
σ²	**1.50**	1.7	1.2	1.7	1.7	0.0	1.5	1.7	1.2



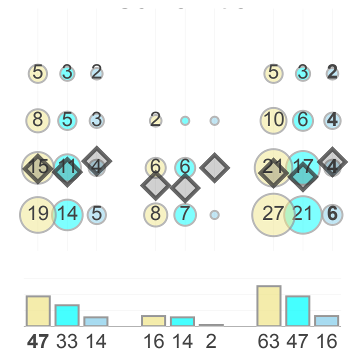
2.53(mean) Z3 emp-c-tele

	1st			2nd			both		
Ø	**2.53**	2.6	2.4	2.4	2.5	2.0	2.5	2.6	2.3
σ	**1.08**	1.0	1.2	1.4	1.4	1.4	1.1	1.1	1.2
σ²	**1.17**	1.1	1.5	1.9	2.0	2.0	1.3	1.3	1.4



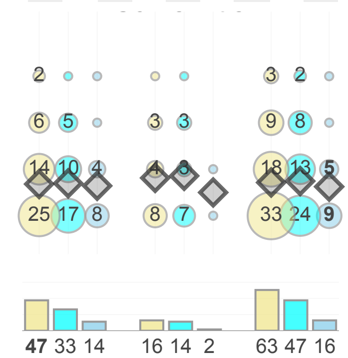
1.98(mean) H3 emp-n-au10

	1st			2nd			both		
Ø	**1.98**	1.9	2.1	1.6	1.6	2.0	1.9	1.8	2.1
σ	**1.01**	1.0	1.1	0.7	0.6	1.4	1.0	0.9	1.1
σ²	**1.02**	1.0	1.2	0.5	0.4	2.0	0.9	0.8	1.2



1.68(mean) D3 emp-c-pulp

	1st			2nd			both		
Ø	**1.68**	1.7	1.6	1.8	1.9	1.5	1.7	1.7	1.6
σ	**0.86**	0.8	0.9	1.0	1.0	0.7	0.9	0.9	0.9
σ²	**0.74**	0.7	0.9	1.0	1.1	0.5	0.8	0.8	0.8

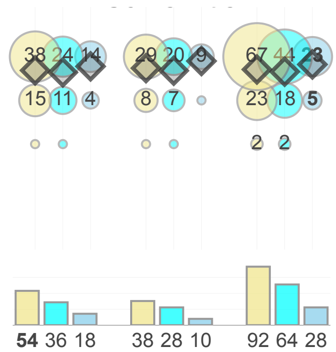


Y1 - Expo 2010 Denmark Pavilion (Shanghai)

(page 1/2)

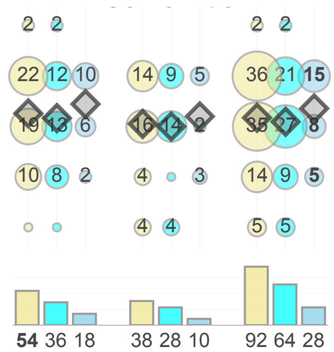
4.69(mean) Y2 emp-c-gm

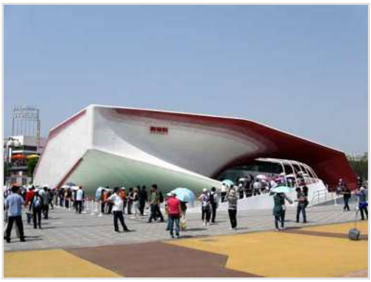
	1st			2nd			both		
Ø	**4.69**	4.6	4.8	4.7	4.7	4.9	4.7	4.7	4.8
σ	**0.51**	0.5	0.4	0.5	0.5	0.3	0.5	0.5	0.4
σ^2	**0.26**	0.3	0.2	0.3	0.3	0.1	0.3	0.3	0.2



3.26(mean) W1 host-culture

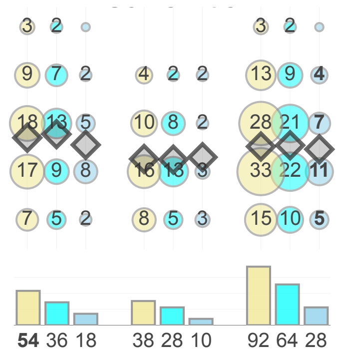
	1st			2nd			both		
Ø	**3.26**	3.2	3.4	3.1	3.0	3.2	3.2	3.1	3.4
σ	**0.87**	0.9	0.7	1.0	1.0	0.9	0.9	1.0	0.8
σ^2	**0.76**	0.9	0.5	0.9	1.0	0.8	0.8	0.9	0.6





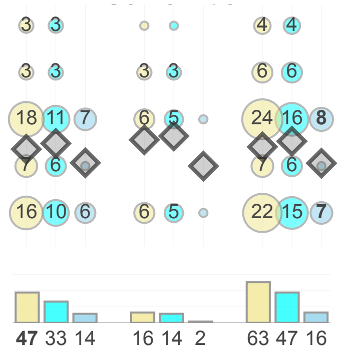
2.70(mean) Y3 emp-n-at10

	1st			2nd			both		
Ø	**2.70**	2.8	2.6	2.3	2.3	2.3	2.5	2.5	2.5
σ	**1.08**	1.1	1.0	0.9	0.8	1.2	1.0	1.0	1.1
σ^2	**1.16**	1.2	1.1	0.8	0.7	1.3	1.1	1.0	1.1



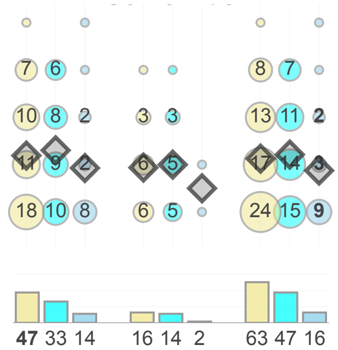
2.36(mean) X1 t-tours

	1st			2nd			both		
Ø	**2.36**	2.5	2.1	2.6	2.6	2.0	2.4	2.5	2.1
σ	**1.21**	1.3	1.0	1.4	1.4	1.4	1.2	1.3	1.0
σ^2	**1.45**	1.6	1.0	1.9	1.9	2.0	1.5	1.7	1.0



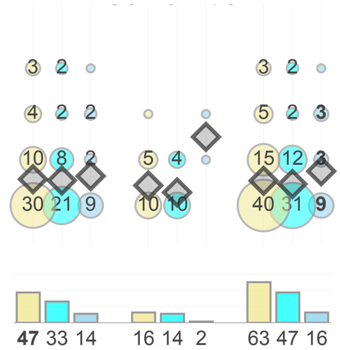
2.19(mean) B1 emp-n-su70

	1st			2nd			both		
Ø	**2.19**	2.3	1.9	1.9	2.0	1.5	2.1	2.2	1.9
σ	**1.17**	1.1	1.3	0.9	1.0	0.7	1.1	1.1	1.3
σ^2	**1.38**	1.2	1.8	0.9	0.9	0.5	1.2	1.1	1.6



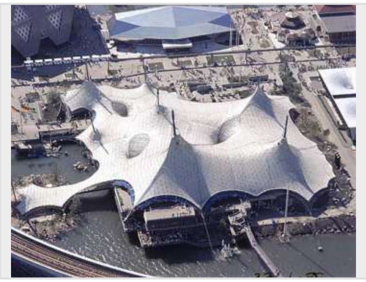
1.57(mean) G1 emp-n-su67

	1st			2nd			both		
Ø	**1.57**	1.5	1.6	1.4	1.3	2.5	1.5	1.5	1.8
σ	**0.90**	0.9	1.0	0.6	0.5	0.7	0.8	0.8	1.0
σ^2	**0.82**	0.8	1.0	0.4	0.2	0.5	0.7	0.6	1.0



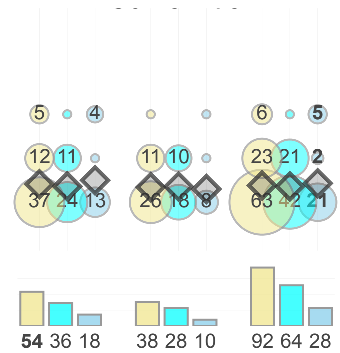
Y1 - Expo 2010 Denmark Pavilion (Shanghai)

(page 2/2)



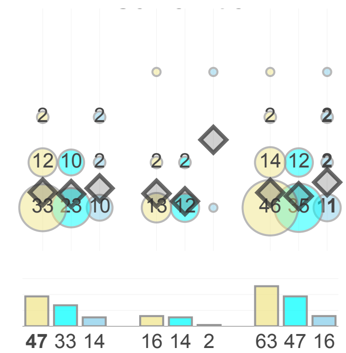
1.41(mean) Z1 emp-n-de67

	1st			2nd			both		
Ø	**1.41**	1.4	1.5	1.3	1.4	1.3	1.4	1.4	1.4
σ	**0.66**	0.5	0.9	0.5	0.5	0.7	0.6	0.5	0.8
σ²	**0.43**	0.3	0.7	0.3	0.2	0.5	0.4	0.3	0.6



1.34(mean) U1 emp-n-nl67

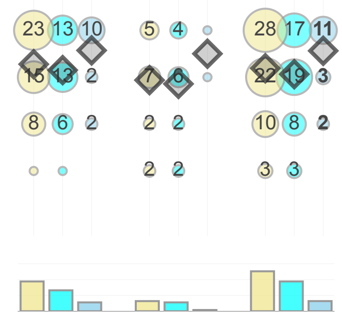
	1st			2nd			both		
Ø	**1.34**	1.3	1.4	1.3	1.1	2.5	1.3	1.3	1.6
σ	**0.56**	0.5	0.8	0.8	0.4	2.1	0.6	0.4	1.0
σ²	**0.32**	0.2	0.6	0.6	0.1	4.5	0.4	0.2	0.9



Y2 - Expo 2010 General Motors Corporate Pav. (Shanghai)

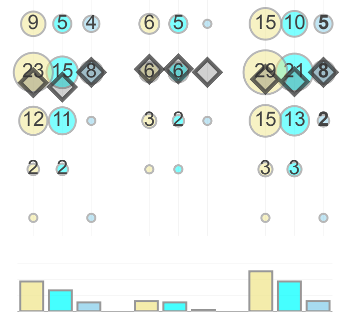
4.28(mean) S2 emp-n-fi

		1st			2nd			both		
Ø	**4.28**	4.2	4.6	3.9	3.9	4.5	4.2	4.1	4.6	
σ	**0.83**	0.8	0.8	1.0	1.0	0.7	0.9	0.9	0.7	
σ²	**0.68**	0.7	0.6	1.0	1.1	0.5	0.8	0.8	0.5	



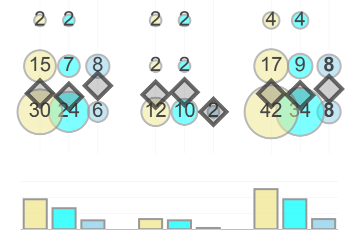
3.79(mean) X2 c-brewers

		1st			2nd			both		
Ø	**3.79**	3.7	4.0	4.1	4.1	4.0	3.9	3.8	4.0	
σ	**0.88**	0.8	1.0	0.9	0.9	1.4	0.9	0.9	1.0	
σ²	**0.78**	0.7	1.1	0.9	0.8	2.0	0.8	0.7	1.1	



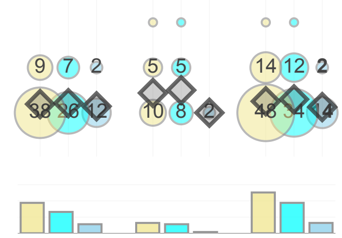
1.40(mean) E2 host-cn

		1st			2nd			both		
Ø	**1.40**	1.3	1.6	1.4	1.4	1.0	1.4	1.4	1.5	
σ	**0.58**	0.6	0.5	0.7	0.8	0.0	0.6	0.6	0.5	
σ²	**0.33**	0.4	0.3	0.5	0.6	0.0	0.4	0.4	0.3	

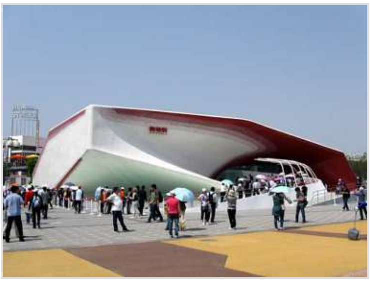


1.19(mean) B2 emp-n-uk

		1st			2nd			both		
Ø	**1.19**	1.2	1.1	1.4	1.5	1.0	1.3	1.3	1.1	
σ	**0.40**	0.4	0.4	0.6	0.7	0.0	0.5	0.5	0.3	
σ²	**0.16**	0.2	0.1	0.4	0.4	0.0	0.2	0.3	0.1	

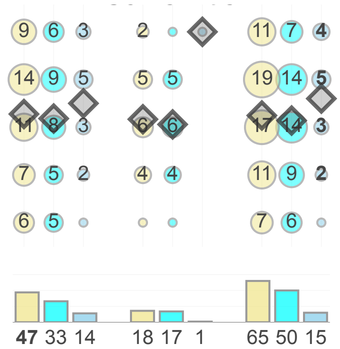


Y3 - Expo 2010 Austria Pavilion (Shanghai)



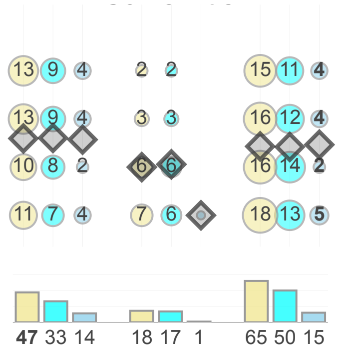
3.28(mean) A3 g-europe

	1st			2nd			both		
Ø	**3.28**	3.2	3.5	3.2	3.1	5.0	3.2	3.1	3.6
σ	**1.30**	1.3	1.2	1.1	1.0	0.0	1.2	1.2	1.2
σ²	**1.68**	1.8	1.5	1.2	1.1	0.0	1.5	1.5	1.5



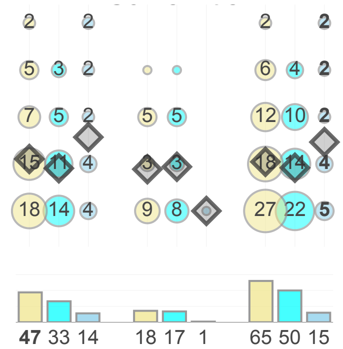
2.60(mean) W3 t-future

	1st			2nd			both		
Ø	**2.60**	2.6	2.6	2.0	2.1	1.0	2.4	2.4	2.5
σ	**1.14**	1.1	1.2	1.0	1.0	0.0	1.1	1.1	1.2
σ²	**1.29**	1.2	1.5	1.1	1.1	0.0	1.3	1.2	1.6



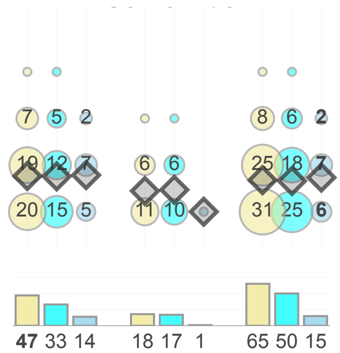
2.11(mean) S3 emp-n-cz

	1st			2nd			both		
Ø	**2.11**	1.9	2.6	1.9	1.9	1.0	2.0	1.9	2.5
σ	**1.17**	1.0	1.5	1.0	1.0	0.0	1.1	1.0	1.5
σ²	**1.36**	1.0	2.1	1.0	1.1	0.0	1.3	1.0	2.1

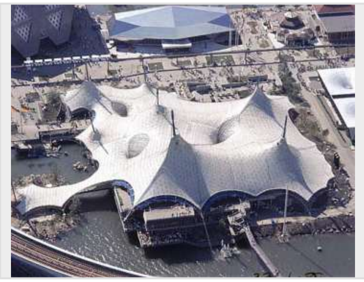


1.77(mean) E3 c-chemical

	1st			2nd			both		
Ø	**1.77**	1.8	1.8	1.4	1.5	1.0	1.7	1.7	1.7
σ	**0.79**	0.8	0.7	0.6	0.6	0.0	0.8	0.8	0.7
σ²	**0.62**	0.7	0.5	0.4	0.4	0.0	0.6	0.6	0.5



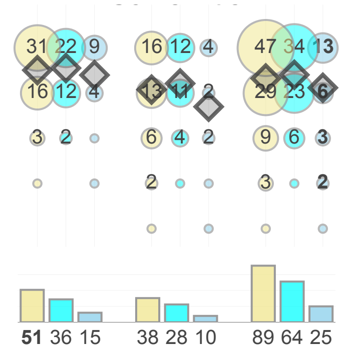
Z1 - Expo 1967 Germany Pavilion (Montreal)



(page 1/2)

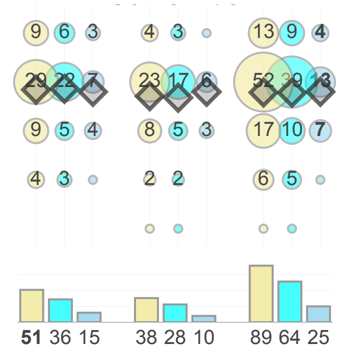
4.51(mean) Z2 emp-n-no

	1st			2nd			both		
Ø	**4.51**	4.6	4.4	4.1	4.2	3.7	4.3	4.4	4.1
σ	**0.70**	0.6	0.9	1.0	0.8	1.4	0.9	0.7	1.2
σ²	**0.49**	0.4	0.8	1.0	0.7	2.0	0.8	0.5	1.4



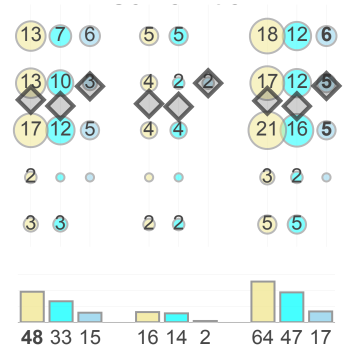
3.84(mean) Z3 emp-c-tele

	1st			2nd			both		
Ø	**3.84**	3.9	3.8	3.7	3.7	3.8	3.8	3.8	3.8
σ	**0.81**	0.8	0.9	0.8	0.9	0.6	0.8	0.8	0.8
σ²	**0.65**	0.6	0.7	0.7	0.8	0.4	0.7	0.7	0.6



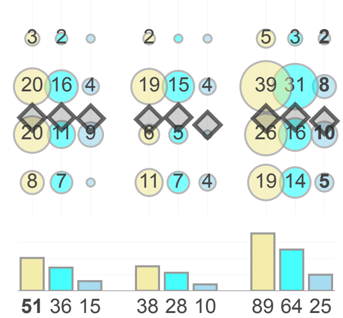
3.65(mean) V1 emp-n-at67

	1st			2nd			both		
Ø	**3.65**	3.5	3.9	3.6	3.5	4.0	3.6	3.5	3.9
σ	**1.12**	1.1	1.0	1.4	1.5	0.0	1.2	1.2	1.0
σ²	**1.25**	1.3	1.1	1.9	2.1	0.0	1.4	1.5	0.9



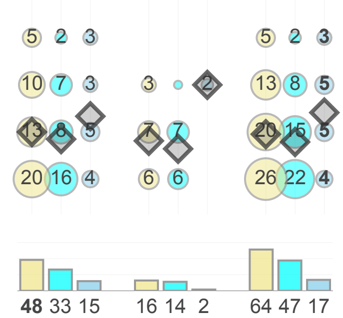
2.35(mean) X1 t-tours

	1st			2nd			both		
Ø	**2.35**	2.4	2.3	2.3	2.4	2.2	2.3	2.4	2.3
σ	**0.82**	0.9	0.7	1.0	0.9	1.1	0.9	0.9	0.9
σ²	**0.67**	0.8	0.5	0.9	0.8	1.3	0.8	0.8	0.8



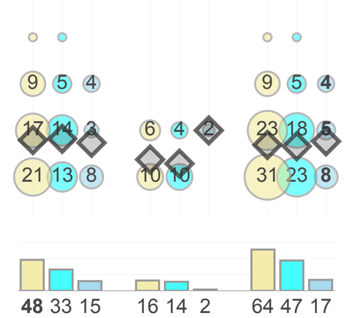
2.00(mean) A1 emp-n-ca10

	1st			2nd			both		
Ø	**2.00**	1.8	2.3	1.8	1.6	3.0	2.0	1.8	2.4
σ	**1.03**	1.0	1.1	0.8	0.6	0.0	1.0	0.9	1.1
σ²	**1.06**	0.9	1.2	0.6	0.4	0.0	0.9	0.8	1.1



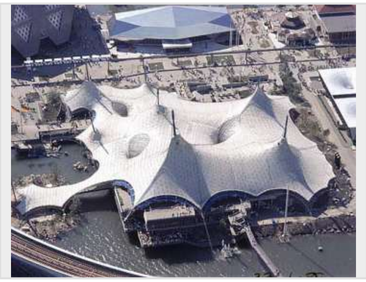
1.79(mean) H1 emp-n-cl

	1st			2nd			both		
Ø	**1.79**	1.8	1.7	1.4	1.3	2.0	1.7	1.7	1.8
σ	**0.82**	0.8	0.9	0.5	0.5	0.0	0.8	0.8	0.8
σ²	**0.68**	0.7	0.8	0.3	0.2	0.0	0.6	0.6	0.7



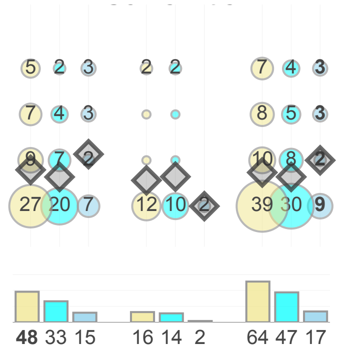
Z1 - Expo 1967 Germany Pavilion (Montreal)

(page 2/2)



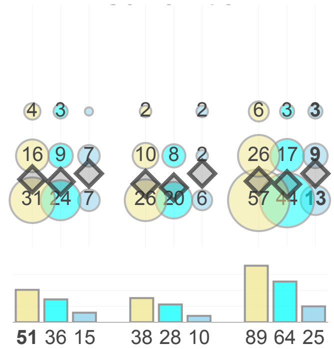
1.79(mean) W1 host-culture

	1st			2nd			both		
Ø	**1.79**	1.6	2.1	1.6	1.6	1.0	1.7	1.6	2.0
σ	**1.05**	0.9	1.2	1.1	1.2	0.0	1.1	1.0	1.2
σ^2	**1.10**	0.9	1.6	1.2	1.3	0.0	1.1	1.0	1.5



1.47(mean) Y1 emp-n-dk

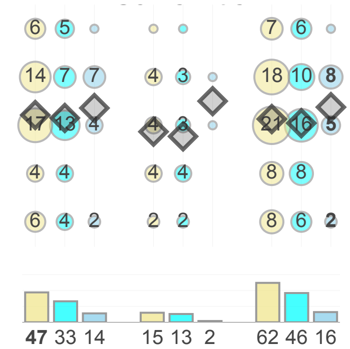
	1st			2nd			both		
Ø	**1.47**	1.4	1.6	1.4	1.3	1.6	1.4	1.4	1.6
σ	**0.64**	0.6	0.6	0.6	0.5	0.8	0.6	0.6	0.7
σ^2	**0.41**	0.4	0.4	0.3	0.2	0.7	0.4	0.3	0.5



Z2 - Expo 2010 Norway Pavilion (Shanghai)

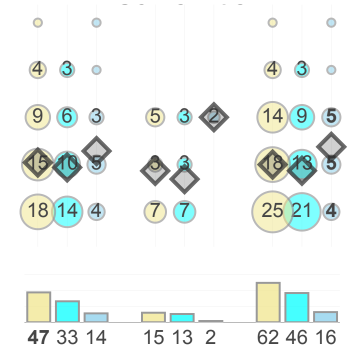
3.21(mean) A2 emp-n-de10

	1st			2nd			both		
Ø	**3.21**	3.2	3.4	2.9	2.8	3.5	3.1	3.0	3.4
σ	**1.18**	1.2	1.2	1.2	1.2	0.7	1.2	1.2	1.1
σ²	**1.39**	1.4	1.3	1.4	1.5	0.5	1.4	1.5	1.2



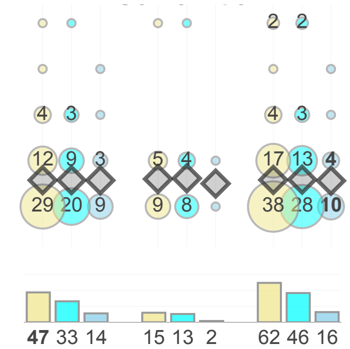
2.04(mean) T2 emp-c-oil

	1st			2nd			both		
Ø	**2.04**	1.9	2.3	1.9	1.7	3.0	2.0	1.9	2.4
σ	**1.06**	1.0	1.2	0.9	0.9	0.0	1.0	1.0	1.1
σ²	**1.13**	1.0	1.5	0.8	0.7	0.0	1.0	0.9	1.3



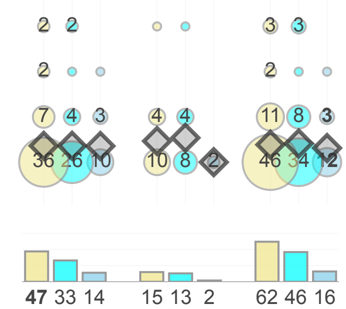
1.57(mean) W2 emp-n-sg

	1st			2nd			both		
Ø	**1.57**	1.6	1.6	1.6	1.6	1.5	1.6	1.6	1.6
σ	**0.90**	0.9	0.9	1.1	1.1	0.7	0.9	1.0	0.9
σ²	**0.82**	0.8	0.9	1.1	1.3	0.5	0.9	0.9	0.8



1.36(mean) F2 emp-n-jp10

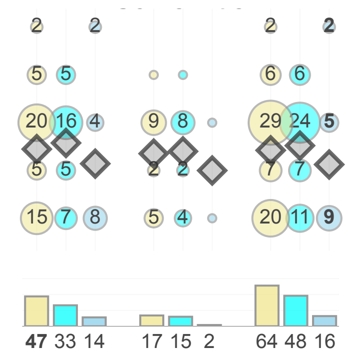
	1st			2nd			both		
Ø	**1.36**	1.4	1.4	1.5	1.5	1.0	1.4	1.4	1.3
σ	**0.76**	0.8	0.6	0.8	0.9	0.0	0.8	0.8	0.6
σ²	**0.58**	0.7	0.4	0.7	0.8	0.0	0.6	0.7	0.4



Z3 - Expo 1970 Telecommunication Corporate Pav. (Osaka)

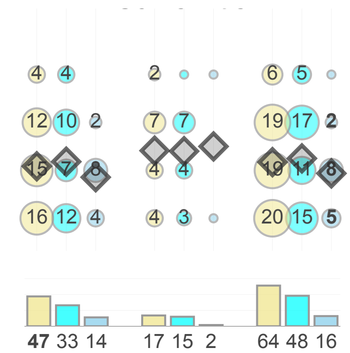
2.45(mean) X3 emp-n-fr70

		1st			2nd			both	
Ø	**2.45**	2.6	2.1	2.4	2.4	2.0	2.4	2.5	2.1
σ	**1.18**	1.0	1.5	1.0	1.0	1.4	1.1	1.0	1.5
σ²	**1.38**	1.0	2.3	1.0	1.0	2.0	1.3	1.0	2.1



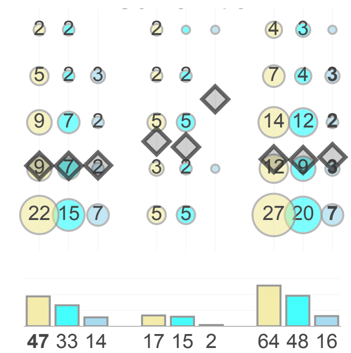
2.09(mean) F3 emp-n-jp00

		1st			2nd			both	
Ø	**2.09**	2.2	1.9	2.4	2.4	2.5	2.2	2.3	1.9
σ	**0.97**	1.1	0.7	1.0	0.9	2.1	1.0	1.0	0.9
σ²	**0.95**	1.2	0.4	1.0	0.8	4.5	1.0	1.0	0.7



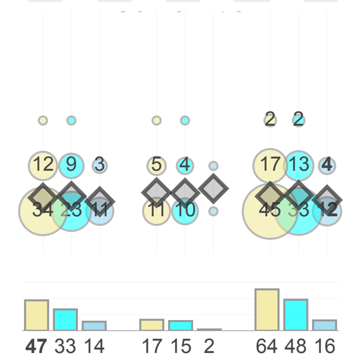
2.06(mean) B3 emp-n-ph

		1st			2nd			both	
Ø	**2.06**	2.1	2.1	2.6	2.5	3.5	2.2	2.2	2.3
σ	**1.22**	1.2	1.3	1.4	1.3	2.1	1.3	1.2	1.4
σ²	**1.50**	1.5	1.6	1.9	1.7	4.5	1.6	1.6	1.9



1.30(mean) T3 c-posco

		1st			2nd			both	
Ø	**1.30**	1.3	1.2	1.4	1.4	1.5	1.3	1.4	1.3
σ	**0.51**	0.5	0.4	0.6	0.6	0.7	0.5	0.6	0.4
σ²	**0.26**	0.3	0.2	0.4	0.4	0.5	0.3	0.3	0.2



This page intentionally left blank in print layout

Appendix D

Data Gathering Screens

part of doctoral thesis

Building Shape Classification

Philipp Jurewicz 2023

Note about image references:

This appendix is part of the doctoral thesis “Building Shape Classification” at TU Wien. This appendix contains 80 photographs of World Exposition pavilions. Please also see the chapter “18. Image References” in the main document to understand the methodology. The section titled “80 Default Photographs of the 80 World Exposition Pavilions“ in chapter 18 covers the bigger photographs used in this appendix. The photograph origins of the small thumbnails below the right hand side photographs are documented on the last pages of Appendix A.

A1 - Expo 2010 Canada Pavilion (Shanghai)

group:	**A - Faceted**	appears as focus in:	**A1ä, A1ö, A1ü, (see screenshots below)**
type:	**Nation Pavilion**	appears as compare in:	**B1ä, C1ö, D1ä, U1ß, Z1ß,**
prj-id:	**prj2110**	(also appears as focus in):	**A1â, K1ä,**
emp-id:	**emp-n-ca10**	(also appears as compare in):	**J3ê, J7ê, K5ä, K8ä,**

Plate A1ä

focus: **A1 - Canada (2010)**

top left: **A3 - Europe**
top right: **D1 - Ontario**
bottom left: **A2 - Germany (2010)**
bottom right: **B1 - Soviet Union (1970)**

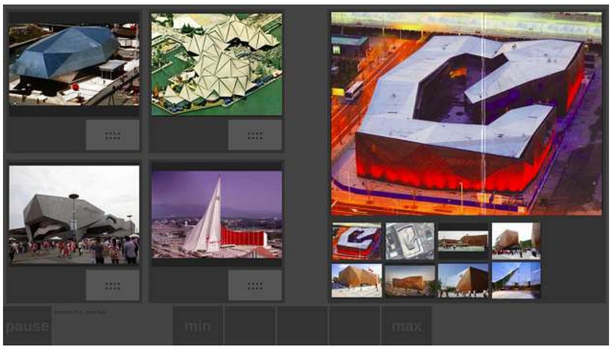


Plate A1ö

focus: **A1 - Canada (2010)**

top left: **A5 - Venezuela**
top right: **C2 - Algeria**
bottom left: **A4 - Russia**
bottom right: **C1 - Angola**

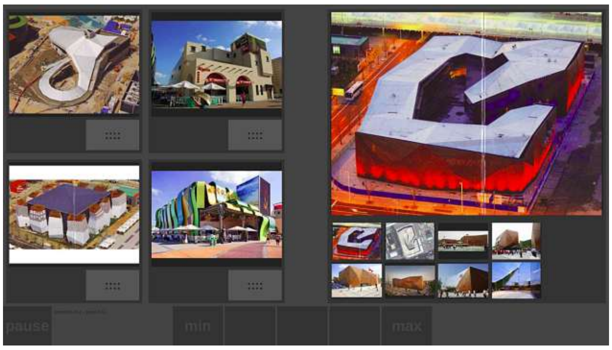
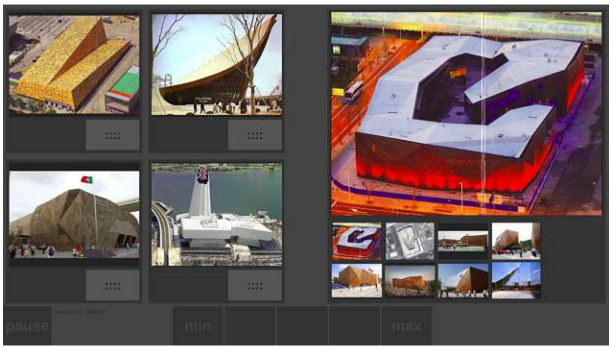


Plate A1ü

focus: **A1 - Canada (2010)**

top left: **A7 - Poland**
top right: **B3 - Philippines**
bottom left: **A6 - Portugal**
bottom right: **B2 - United Kingdom**



A2 - Expo 2010 Germany Pavilion (Shanghai)

group:	**A - Faceted**	appears as focus in:	**A2ä, A2ö, (see screenshots below)**
type:	**Nation Pavilion**	appears as compare in:	**A1ä, A3ä, C1ö, C2ä, C3ä, D1ü, T2ü, Z2ü,**
prj-id:	**prj2116**		
emp-id:	**emp-n-de10**	(also appears as focus in):	**M1ö,**
		(also appears as compare in):	**A1â, J7â, J7ê, M6ä, M7ä,**

Plate A2ä

focus: **A2 - Germany (2010)**

top left: **A6 - Portugal**
top right: **D2 - Africa**
bottom left: **A4 - Russia**
bottom right: **B2 - United Kingdom**

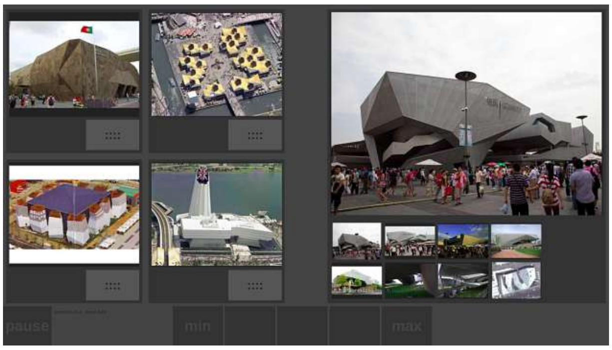
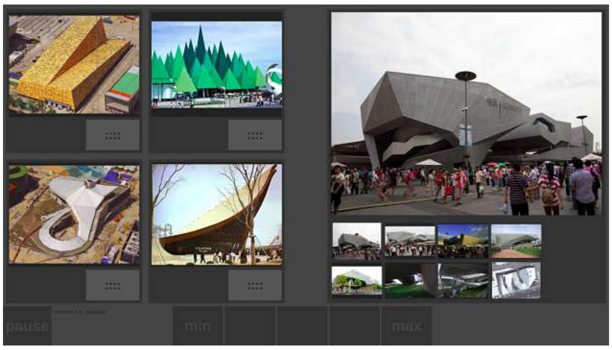


Plate A2ö

focus: **A2 - Germany (2010)**

top left: **A7 - Poland**
top right: **D3 - Pulp and Paper**
bottom left: **A5 - Venezuela**
bottom right: **B3 - Philippines**



A3 - Expo 1967 Europe Pavilion (Montreal)

group:	**A - Faceted**	appears as focus in:	**A3ä, A3ö, (see screenshots below)**
type:	**Group Pavilion**	appears as compare in:	**A1ä, B2ö, C3ö, D1ü, D2ö, V3ü, Y3ü,**
prj-id:	**prj2513**	(also appears as focus in):	**N1ä,**
emp-id:	**emp-g-europe**	(also appears as compare in):	**A1â, J7â, N5ä, N8ä,**

Plate A3ä

focus: **A3 - Europe**

top left: **A7 - Poland**
top right: **C2 - Algeria**
bottom left: **A4 - Russia**
bottom right: **A2 - Germany (2010)**

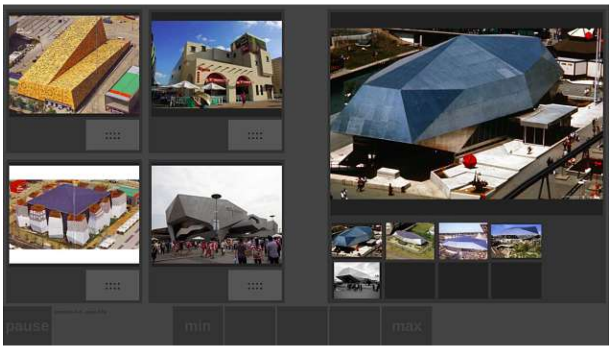
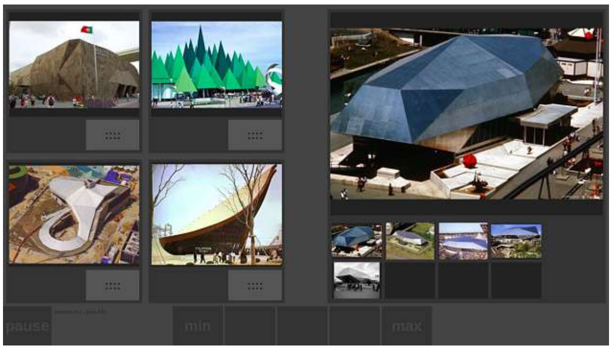


Plate A3ö

focus: **A3 - Europe**

top left: **A6 - Portugal**
top right: **D3 - Pulp and Paper**
bottom left: **A5 - Venezuela**
bottom right: **B3 - Philippines**



B1 - Expo 1970 Soviet Union Pavilion (Osaka)

group:	**B - Spike**	appears as focus in:	**B1ä, B1ö, B1ü, (see screenshots below)**
type:	**Nation Pavilion**	appears as compare in:	**A1ä, C1ä, D1ö, V1ß, Y1ß,**
prj-id:	**prj3134**	(also appears as focus in):	**B1â, J7â, K2ö,**
emp-id:	**emp-n-su70**	(also appears as compare in):	**J3ê, K5ä, K8ä,**

Plate B1ä

focus: **B1 - Soviet Union (1970)**

top left: **B3 - Philippines**
top right: **A1 - Canada (2010)**
bottom left: **B2 - United Kingdom**
bottom right: **C1 - Angola**

Plate B1ö

focus: **B1 - Soviet Union (1970)**

top left: **B5 - Luxembourg**
top right: **D2 - Africa**
bottom left: **B4 - Malaysia**
bottom right: **D1 - Ontario**

Plate B1ü

focus: **B1 - Soviet Union (1970)**

top left: **B7 - Philips**
top right: **C3 - France (1967)**
bottom left: **B6 - Civil Enginnering**
bottom right: **C2 - Algeria**

B2 - Expo 1967 United Kingdom Pavilion (Montreal)

group:	**B - Spike**	appears as focus in:	**B2ä, B2ö, (see screenshots below)**
type:	**Nation Pavilion**	appears as compare in:	**A1ü, A2ä, B1ä, B3ä, D1ö, D2ä, D3ä, S2ü, Y2ü,**
prj-id:	**prj2432**		
emp-id:	**emp-n-uk**	(also appears as focus in):	**M2ä,**
		(also appears as compare in):	**B1â, M6ä, M7ä,**

Plate B2ä

focus: **B2 - United Kingdom**

top left: **B6 - Civil Enginnering**
top right: **A4 - Russia**
bottom left: **B4 - Malaysia**
bottom right: **C2 - Algeria**

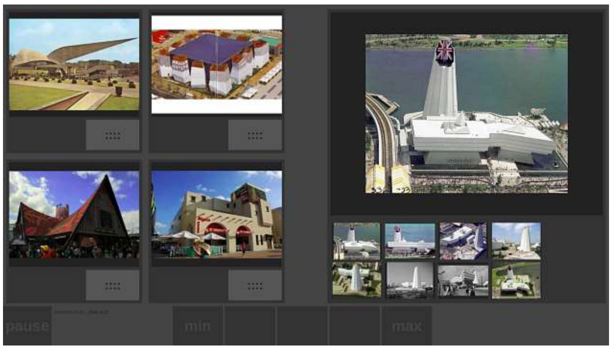
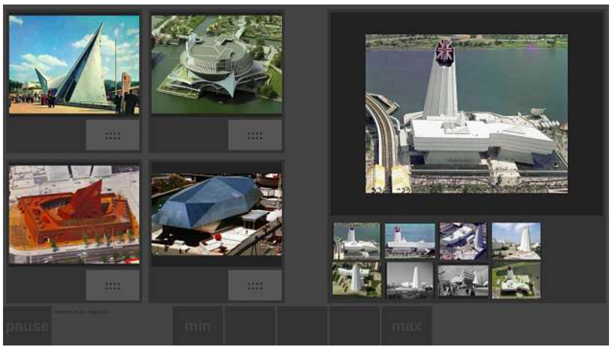


Plate B2ö

focus: **B2 - United Kingdom**

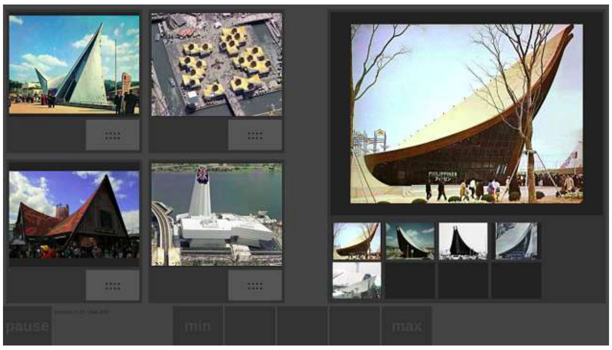
top left: **B7 - Philips**
top right: **C3 - France (1967)**
bottom left: **B5 - Luxembourg**
bottom right: **A3 - Europe**



B3 - Expo 1970 Philippines Pavilion (Osaka)

group:	B - Spike	appears as focus in:	B3ä, B3ö, (see screenshots below)
type:	Nation Pavilion	appears as compare in:	A1ü, A2ö, A3ö, B1ä, C2ö, D3ö, S3ü, Z3ü,
prj-id:	prj3131		
emp-id:	emp-n-ph	(also appears as focus in):	N2ö,
		(also appears as compare in):	B1â, N5ä, N8ä,

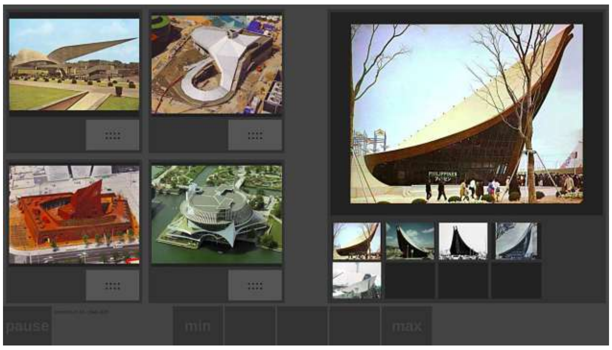
Plate B3ä



focus: **B3 - Philippines**

top left: **B7 - Philips**
top right: **D2 - Africa**
bottom left: **B4 - Malaysia**
bottom right: **B2 - United Kingdom**

Plate B3ö



focus: **B3 - Philippines**

top left: **B6 - Civil Enginnering**
top right: **A5 - Venezuela**
bottom left: **B5 - Luxembourg**
bottom right: **C3 - France (1967)**

C1 - Expo 2010 Angola Pavilion (Shanghai)

group:	**C - Hidden Simple**	appears as focus in:	**C1ä, C1ö, C1ü, (see screenshots below)**
type:	**Nation Pavilion**	appears as compare in:	**A1ö, B1ä, D1ä, S1ß, W1ß,**
prj-id:	**prj2101**	(also appears as focus in):	**C1â, K3ü,**
emp-id:	**emp-n-ao**	(also appears as compare in):	**K5ä, K8ä,**

Plate C1ä

focus: **C1 - Angola**

top left: **C3 - France (1967)**
top right: **B1 - Soviet Union (1970)**
bottom left: **C2 - Algeria**
bottom right: **D1 - Ontario**

Plate C1ö

focus: **C1 - Angola**

top left: **C5 - Israel**
top right: **A2 - Germany (2010)**
bottom left: **C4 - Monaco**
bottom right: **A1 - Canada (2010)**

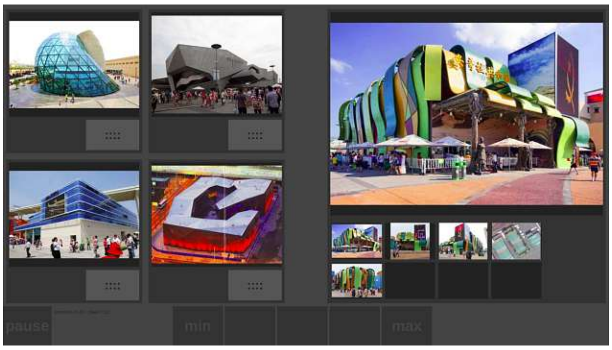
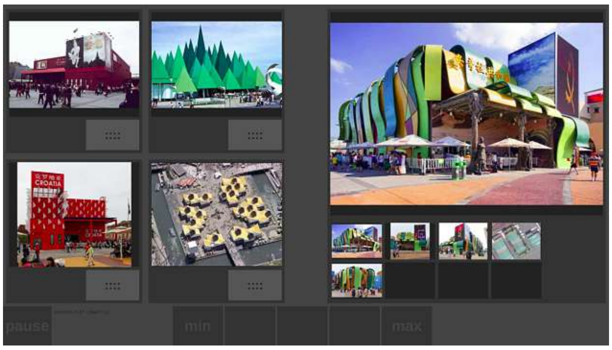


Plate C1ü

focus: **C1 - Angola**

top left: **C7 - Sri Lanka**
top right: **D3 - Pulp and Paper**
bottom left: **C6 - Croatia**
bottom right: **D2 - Africa**



C2 - Expo 2010 Algeria Pavilion (Shanghai)

group:	**C - Hidden Simple**	appears as focus in:	**C2ä, C2ö, (see screenshots below)**
type:	**Nation Pavilion**	appears as compare in:	**A1ö, A3ä, B1ü, B2ä, C1ä, C3ä, U2ü, W2ü,**
prj-id:	**prj2118**		
emp-id:	**emp-n-dz**	(also appears as focus in):	**M3ä,**
		(also appears as compare in):	**C1â, J2â, M6ä, M7ä,**

Plate C2ä

focus: **C2 - Algeria**

top left: **C6 - Croatia**
top right: **D2 - Africa**
bottom left: **C4 - Monaco**
bottom right: **A2 - Germany (2010)**

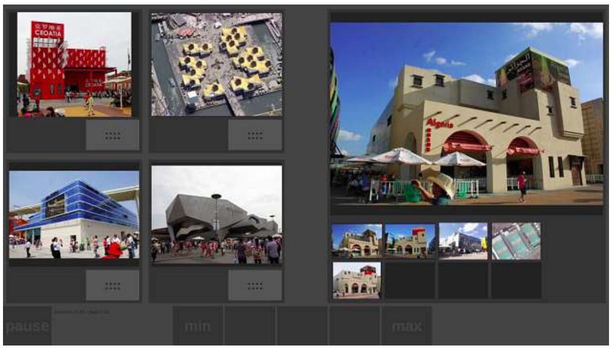
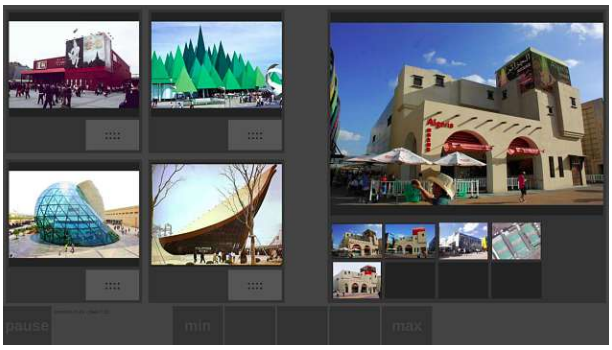


Plate C2ö

focus: **C2 - Algeria**

top left: **C7 - Sri Lanka**
top right: **D3 - Pulp and Paper**
bottom left: **C5 - Israel**
bottom right: **B3 - Philippines**



C3 - Expo 1967 France Pavilion (Montreal)

group:	**C - Hidden Simple**	appears as focus in:	**C3ä, C3ö, (see screenshots below)**
type:	**Nation Pavilion**	appears as compare in:	**B1ü, B2ö, B3ö, C1ä, D2ö, T3ü, W3ü,**
prj-id:	**prj2409**	(also appears as focus in):	**N3ü,**
emp-id:	**emp-n-fr67**	(also appears as compare in):	**C1â, J3â, J4â, J9û, N5ä, N8ä,**

Plate C3ä

focus:	**C3 - France (1967)**
top left:	**C7 - Sri Lanka**
top right:	**C2 - Algeria**
bottom left:	**C4 - Monaco**
bottom right:	**A2 - Germany (2010)**

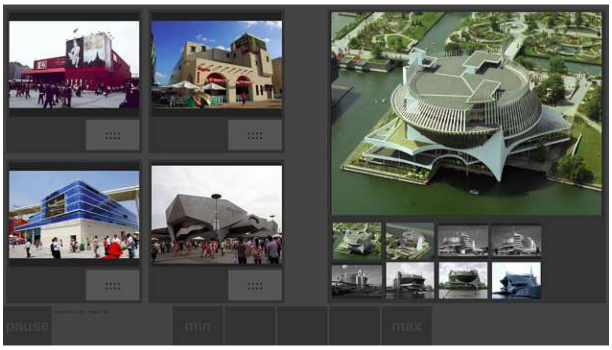


Plate C3ö

focus:	**C3 - France (1967)**
top left:	**C6 - Croatia**
top right:	**D3 - Pulp and Paper**
bottom left:	**C5 - Israel**
bottom right:	**A3 - Europe**

D1 - Expo 1967 Ontario Region Pavilion (Montreal)

group:	**D - Multiple**	appears as focus in:	**D1ä, D1ö, D1ü, (see screenshots below)**
type:	**Region Pavilion**	appears as compare in:	**A1ä, B1ö, C1ä, T1ß, X1ß,**
prj-id:	**prj2354**	(also appears as focus in):	**D1â, K4ä,**
emp-id:	**emp-r-ont**	(also appears as compare in):	**J5â, K5ä, K8ä,**

Plate D1ä

focus: **D1 - Ontario**

top left: **D3 - Pulp and Paper**
top right: **C1 - Angola**
bottom left: **D2 - Africa**
bottom right: **A1 - Canada (2010)**

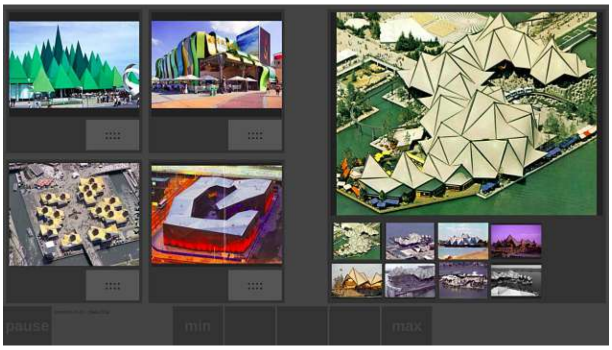


Plate D1ö

focus: **D1 - Ontario**

top left: **D5 - Cases**
top right: **B2 - United Kingdom**
bottom left: **D4 - Wanke**
bottom right: **B1 - Soviet Union (1970)**

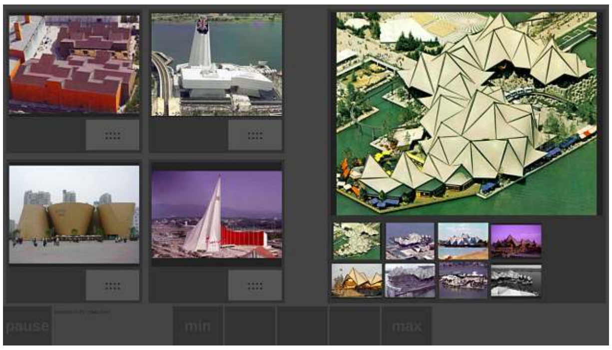
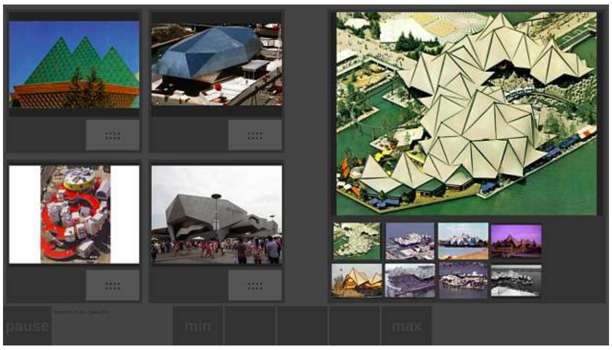


Plate D1ü

focus: **D1 - Ontario**

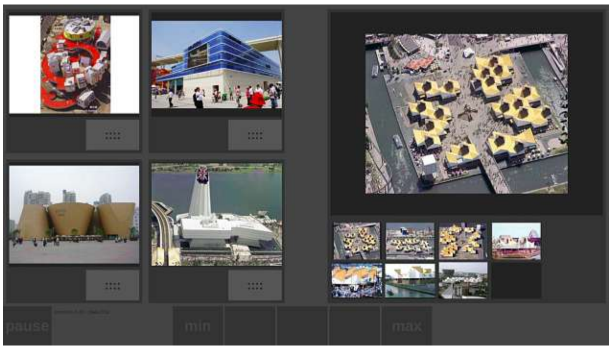
top left: **D7 - Bulgaria**
top right: **A3 - Europe**
bottom left: **D6 - Netherlands (2010)**
bottom right: **A2 - Germany (2010)**



D2 - Expo 1967 Africa Group Pavilion (Montreal)

group:	**D - Multiple**	appears as focus in:	**D2ä, D2ö, (see screenshots below)**
type:	**Group Pavilion**	appears as compare in:	**A2ä, B1ö, B3ä, C1ü, C2ä, D1ä, D3ä, V2ü, X2ü,**
prj-id:	**prj2511**		
emp-id:	**emp-g-africa**	(also appears as focus in):	**J9ê, M4ü,**
		(also appears as compare in):	**D1â, M6ä, M7ä,**

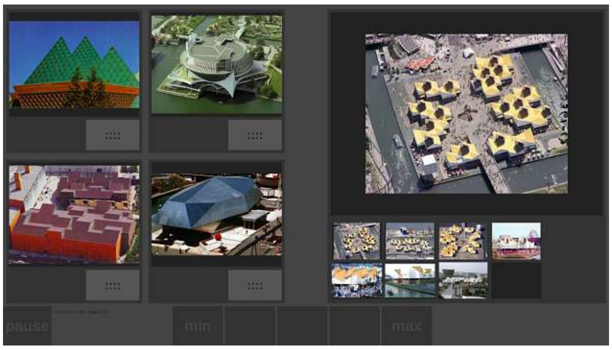
Plate D2ä



focus: **D2 - Africa**

top left: **D6 - Netherlands (2010)**
top right: **C4 - Monaco**
bottom left: **D4 - Wanke**
bottom right: **B2 - United Kingdom**

Plate D2ö



focus: **D2 - Africa**

top left: **D7 - Bulgaria**
top right: **C3 - France (1967)**
bottom left: **D5 - Cases**
bottom right: **A3 - Europe**

D3 - Expo 1967 Pulp and Paper Corporate Pav. (Montreal)

group: **D - Multiple**
type: **Corporate Pavilion**
prj-id: **prj2569**
emp-id: **emp-c-pulp**

appears as focus in: **D3ä, D3ö, (see screenshots below)**
appears as compare in: **A2ö, A3ö, C1ü, C2ö, C3ö, D1ä, U3ü, X3ü,**
(also appears as focus in): **N4ä,**
(also appears as compare in): **D1â, J7ê, N5ä, N8ä,**

Plate D3ä

focus: **D3 - Pulp and Paper**

top left: **D7 - Bulgaria**
top right: **D2 - Africa**
bottom left: **D4 - Wanke**
bottom right: **B2 - United Kingdom**

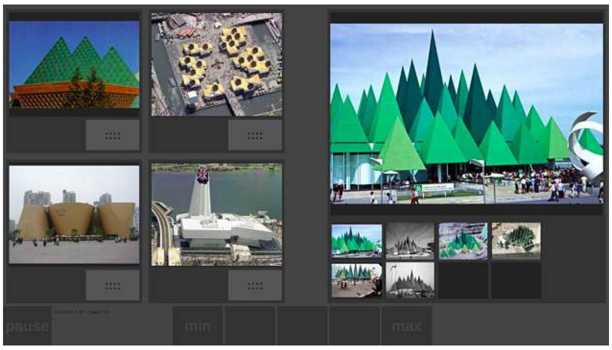


Plate D3ö

focus: **D3 - Pulp and Paper**

top left: **D6 - Netherlands (2010)**
top right: **C5 - Israel**
bottom left: **D5 - Cases**
bottom right: **B3 - Philippines**

E1 - Expo 1967 Canada Host-Pavilion (Montreal)

group:	**E - Cantilever**	appears as focus in:	**E1ä, E1ö, E1ü, (see screenshots below)**
type:	**Host Building**	appears as compare in:	**F1ä, G1ö, H1ä, U1ß, X1ß,**
prj-id:	**prj2301**	(also appears as focus in):	**E1â, K5ä,**
emp-id:	**emp-host-ca**	(also appears as compare in):	**K1ä, K4ä,**

Plate E1ä

focus: **E1 - Canada (1967)**

top left: **E3 - Kaleidoscope**
top right: **H1 - Chile**
bottom left: **E2 - China Host**
bottom right: **F1 - Fuji**

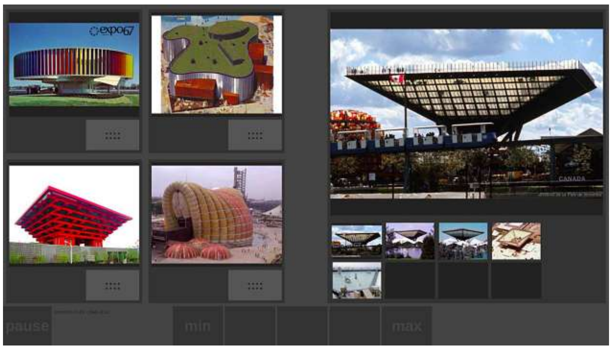


Plate E1ö

focus: **E1 - Canada (1967)**

top left: **E5 - Switzerland**
top right: **G2 - Hyundai**
bottom left: **E4 - Saudi Arabia**
bottom right: **G1 - Soviet Union (1967)**

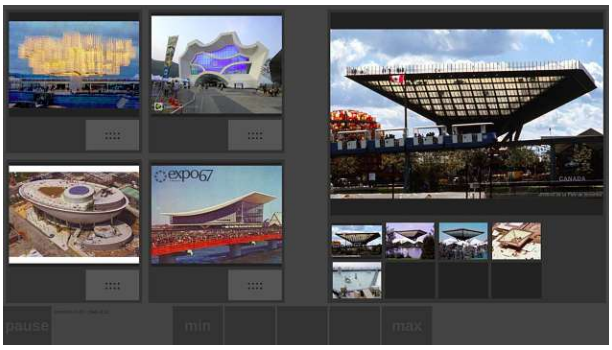
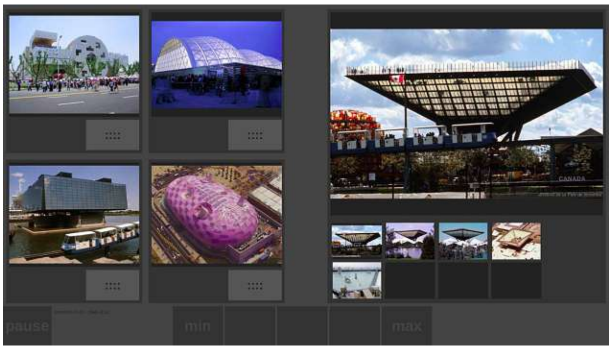


Plate E1ü

focus: **E1 - Canada (1967)**

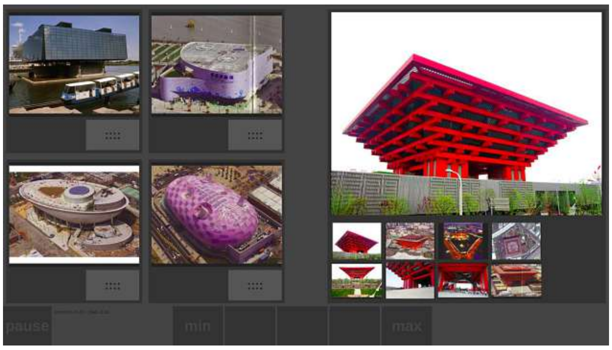
top left: **E7 - South Korea**
top right: **F3 - Japan (2000)**
bottom left: **E6 - Quebec**
bottom right: **F2 - Japan (2010)**



E2 - Expo 2010 China Host Pavilion (Shanghai)

group:	**E - Cantilever**	appears as focus in:	**E2ä, E2ö, (see screenshots below)**
type:	**Host Building**	appears as compare in:	**E1ä, E3ä, G1ö, G2ä, G3ä, H1ü, V2ü, Y2ü,**
prj-id:	**prj2001**		
emp-id:	**emp-host-cn**	(also appears as focus in):	**M5ö,**
		(also appears as compare in):	**E1â, J1â, M2ä, M3ä,**

Plate E2ä



focus:	**E2 - China Host**
top left:	**E6 - Quebec**
top right:	**H2 - Info Communication**
bottom left:	**E4 - Saudi Arabia**
bottom right:	**F2 - Japan (2010)**

Plate E2ö

focus:	**E2 - China Host**
top left:	**E7 - South Korea**
top right:	**H3 - Australia (2010)**
bottom left:	**E5 - Switzerland**
bottom right:	**F3 - Japan (2000)**

E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)

group:	**E - Cantilever**	appears as focus in:	**E3ä, E3ö, (see screenshots below)**
type:	**Corporate Pavilion**	appears as compare in:	**E1ä, F2ö, G3ö, H1ü, H2ö, T3ü, Y3ü,**
prj-id:	**prj2565**	(also appears as focus in):	**J8â, N5ä,**
emp-id:	**emp-c-chemical**	(also appears as compare in):	**E1â, J1â, J9û, N1ä, N4ä,**

Plate E3ä

focus: **E3 - Kaleidoscope**

top left: **E7 - South Korea**
top right: **G2 - Hyundai**
bottom left: **E4 - Saudi Arabia**
bottom right: **E2 - China Host**

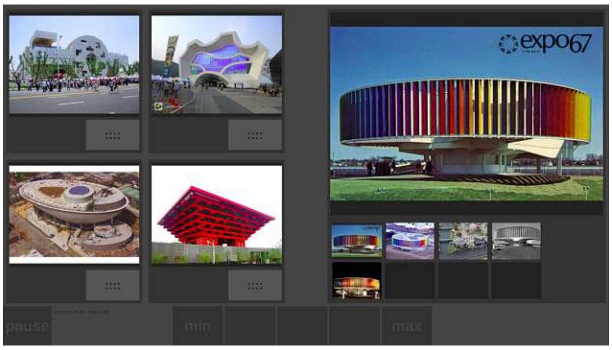
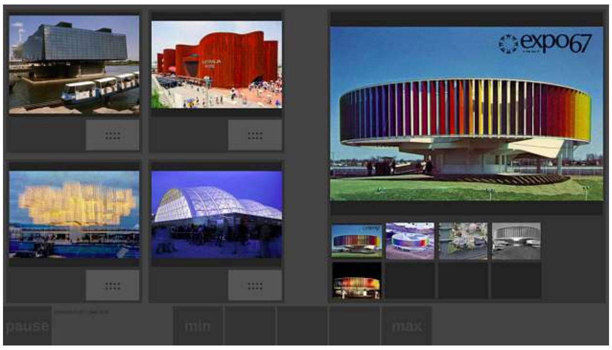


Plate E3ö

focus: **E3 - Kaleidoscope**

top left: **E6 - Quebec**
top right: **H3 - Australia (2010)**
bottom left: **E5 - Switzerland**
bottom right: **F3 - Japan (2000)**



F1 - Expo 1970 Fuji Corporate Pavilion (Osaka)

group:	**F - Blob**	appears as focus in:	**F1ä, F1ö, F1ü, (see screenshots below)**
type:	**Corporate Pavilion**	appears as compare in:	**E1ä, G1ä, H1ö, V1ß, W1ß,**
prj-id:	**prj3244**	(also appears as focus in):	**F1â, J9â, K6ö,**
emp-id:	**emp-c-fuji**	(also appears as compare in):	**J8ê, K1ä, K4ä,**

Plate F1ä

focus: **F1 - Fuji**

top left: **F3 - Japan (2000)**
top right: **E1 - Canada (1967)**
bottom left: **F2 - Japan (2010)**
bottom right: **G1 - Soviet Union (1967)**

Plate F1ö

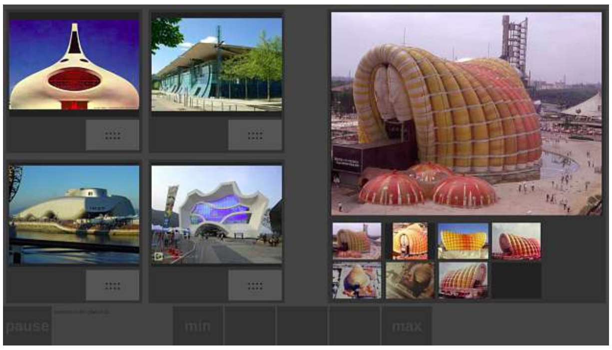
focus: **F1 - Fuji**

top left: **F5 - Aviation**
top right: **H2 - Info Communication**
bottom left: **F4 - Pavilion Of Hope**
bottom right: **H1 - Chile**

Plate F1ü

focus: **F1 - Fuji**

top left: **F7 - Gas**
top right: **G3 - Germany Host**
bottom left: **F6 - Ocean Coast**
bottom right: **G2 - Hyundai**



F2 - Expo 2010 Japan Pavilion (Shanghai)

group:	**F - Blob**	appears as focus in:	**F2ä, F2ö, (see screenshots below)**
type:	**Nation Pavilion**	appears as compare in:	**E1ü, E2ä, F1ä, F3ä, H1ö, H2ä, H3ä, U2ü, Z2ü,**
prj-id:	**prj2134**		
emp-id:	**emp-n-jp10**	(also appears as focus in):	**M6ä,**
		(also appears as compare in):	**F1â, J6ê, J8ê, M2ä, M3ä,**

Plate F2ä

focus: **F2 - Japan (2010)**

top left: **F6 - Ocean Coast**
top right: **E4 - Saudi Arabia**
bottom left: **F4 - Pavilion Of Hope**
bottom right: **G2 - Hyundai**

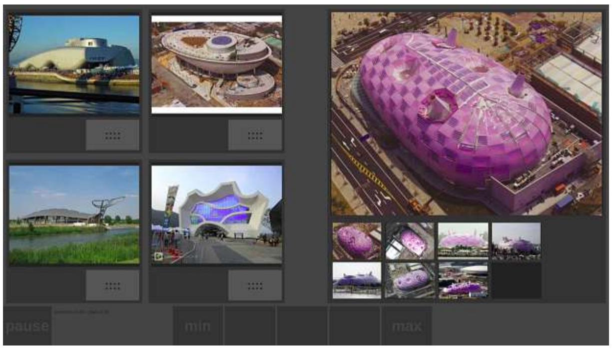
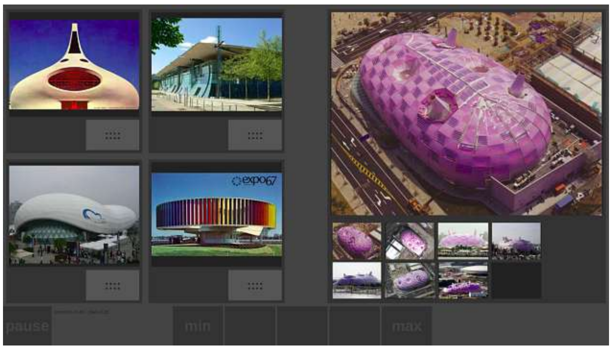


Plate F2ö

focus: **F2 - Japan (2010)**

top left: **F7 - Gas**
top right: **G3 - Germany Host**
bottom left: **F5 - Aviation**
bottom right: **E3 - Kaleidoscope**



F3 - Expo 2000 Japan Pavilion (Hannover)

group:	**F - Blob**	appears as focus in:	**F3ä, F3ö, (see screenshots below)**
type:	**Nation Pavilion**	appears as compare in:	**E1ü, E2ö, E3ö, F1ä, G2ö, H3ö, U3ü, Z3ü,**
prj-id:	**prj3422**		
emp-id:	**emp-n-jp00**	(also appears as focus in):	**J6â, J6ê, N6ö,**
		(also appears as compare in):	**F1â, N1ä, N4ä,**

Plate F3ä

focus: **F3 - Japan (2000)**

top left: **F7 - Gas**
top right: **H2 - Info Communication**
bottom left: **F4 - Pavilion Of Hope**
bottom right: **F2 - Japan (2010)**

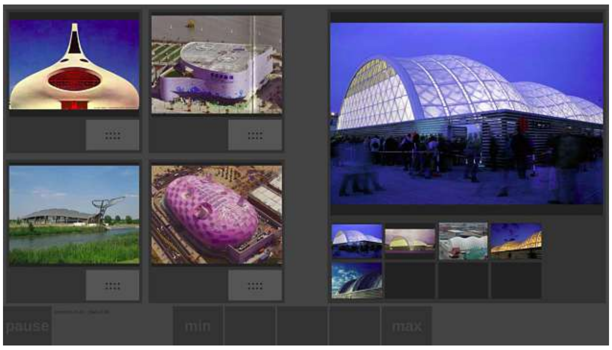
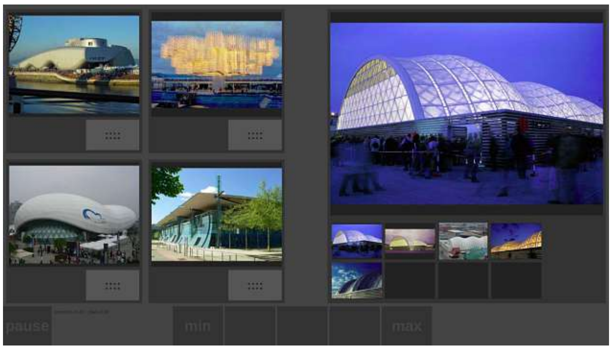


Plate F3ö

focus: **F3 - Japan (2000)**

top left: **F6 - Ocean Coast**
top right: **E5 - Switzerland**
bottom left: **F5 - Aviation**
bottom right: **G3 - Germany Host**



G1 - Expo 1967 Soviet Union Pavilion (Montreal)

group:	**G - Concave**	appears as focus in:	**G1ä, G1ö, G1ü, (see screenshots below)**
type:	**Nation Pavilion**	appears as compare in:	**E1ö, F1ä, H1ä, S1ß, Y1ß,**
prj-id:	**prj2427**	(also appears as focus in):	**G1â, K7ü,**
emp-id:	**emp-n-su67**	(also appears as compare in):	**K1ä, K4ä,**

Plate G1ä

focus: **G1 - Soviet Union (1967)**

top left: **G3 - Germany Host**
top right: **F1 - Fuji**
bottom left: **G2 - Hyundai**
bottom right: **H1 - Chile**

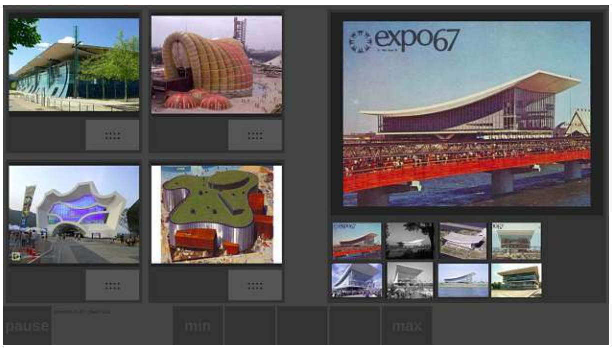


Plate G1ö

focus: **G1 - Soviet Union (1967)**

top left: **G5 - Italy (1967)**
top right: **E2 - China Host**
bottom left: **G4 - Brazil**
bottom right: **E1 - Canada (1967)**

Plate G1ü

focus: **G1 - Soviet Union (1967)**

top left: **G7 - Textiles**
top right: **H3 - Australia (2010)**
bottom left: **G6 - Portugal**
bottom right: **H2 - Info Communication**

G2 - Expo 2012 Hyundai Corporate Pavilion (Yeosu)

group:	**G - Concave**	appears as focus in:	**G2ä, G2ö, (see screenshots below)**
type:	**Corporate Pavilion**	appears as compare in:	**E1ö, E3ä, F1ü, F2ä, G1ä, G3ä, S2ü, X2ü,**
prj-id:	**prj2653**	(also appears as focus in):	**M7ä,**
emp-id:	**emp-c-hyundai**	(also appears as compare in):	**G1â, M2ä, M3ä,**

Plate G2ä

focus: **G2 - Hyundai**

top left: **G6 - Portugal**
top right: **H2 - Info Communication**
bottom left: **G4 - Brazil**
bottom right: **E2 - China Host**

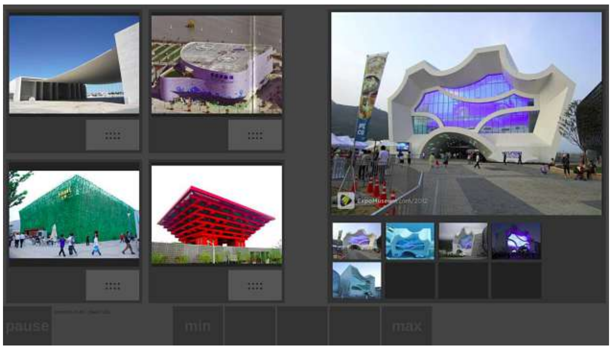


Plate G2ö

focus: **G2 - Hyundai**

top left: **G7 - Textiles**
top right: **H3 - Australia (2010)**
bottom left: **G5 - Italy (1967)**
bottom right: **F3 - Japan (2000)**

G3 - Expo 2000 Germany Host Pavilion (Hannover)

group:	**G - Concave**	appears as focus in:	**G3ä, G3ö, (see screenshots below)**
type:	**Host Building**	appears as compare in:	**F1ü, F2ö, F3ö, G1ä, H2ö, V3ü, W3ü,**
prj-id:	**prj3301**	(also appears as focus in):	**N7ü,**
emp-id:	**emp-host-de**	(also appears as compare in):	**G1â, N1ä, N4ä,**

Plate G3ä

focus: **G3 - Germany Host**

top left: **G7 - Textiles**
top right: **G2 - Hyundai**
bottom left: **G4 - Brazil**
bottom right: **E2 - China Host**

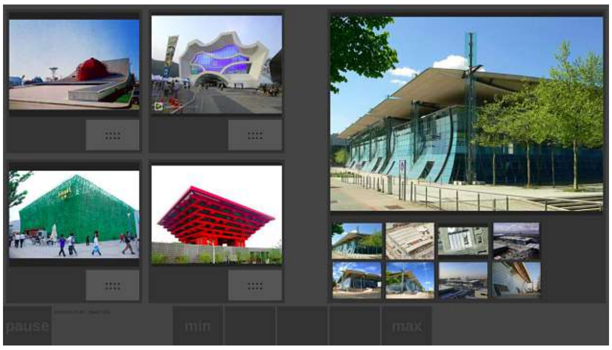


Plate G3ö

focus: **G3 - Germany Host**

top left: **G6 - Portugal**
top right: **H3 - Australia (2010)**
bottom left: **G5 - Italy (1967)**
bottom right: **E3 - Kaleidoscope**

H1 - Expo 2010 Chile Pavilion (Shanghai)

group:	**H - Undulation**	appears as focus in:	**H1ä, H1ö, H1ü, (see screenshots below)**
type:	**Nation Pavilion**	appears as compare in:	**E1ä, F1ö, G1ä, T1ß, Z1ß,**
prj-id:	**prj2112**	(also appears as focus in):	**H1â, K8ä,**
emp-id:	**emp-n-cl**	(also appears as compare in):	**K1ä, K4ä,**

Plate H1ä

focus: **H1 - Chile**

top left: **H3 - Australia (2010)**
top right: **G1 - Soviet Union (1967)**
bottom left: **H2 - Info Communication**
bottom right: **E1 - Canada (1967)**

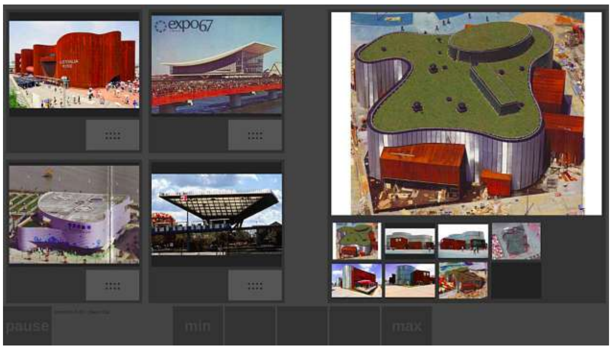


Plate H1ö

focus: **H1 - Chile**

top left: **H5 - Spain**
top right: **F2 - Japan (2010)**
bottom left: **H4 - Private Enterprise**
bottom right: **F1 - Fuji**

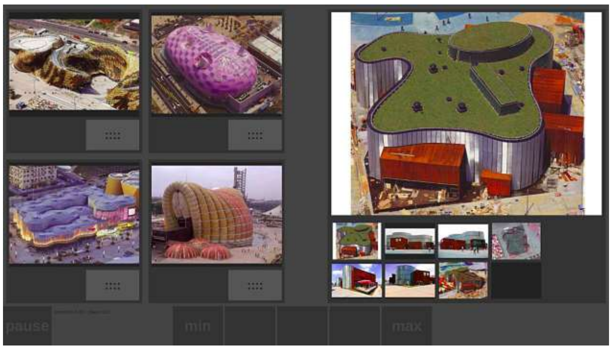


Plate H1ü

focus: **H1 - Chile**

top left: **H7 - Hungary**
top right: **E3 - Kaleidoscope**
bottom left: **H6 - Palaza Del Futuro**
bottom right: **E2 - China Host**

H2 - Expo 2010 Info Communication Corp. Pav. (Shanghai)

group:	**H - Undulation**	appears as focus in:	**H2ä, H2ö, (see screenshots below)**
type:	**Corporate Pavilion**	appears as compare in:	**E2ä, F1ö, F3ä, G1ü, G2ä, H1ä, H3ä, T2ü, W2ü,**
prj-id:	**prj2268**		
emp-id:	**emp-c-info**	(also appears as focus in):	**M8ü,**
		(also appears as compare in):	**H1â, M2ä, M3ä,**

Plate H2ä

focus: **H2 - Info Communication**

top left: **H6 - Palaza Del Futuro**
top right: **G4 - Brazil**
bottom left: **H4 - Private Enterprise**
bottom right: **F2 - Japan (2010)**

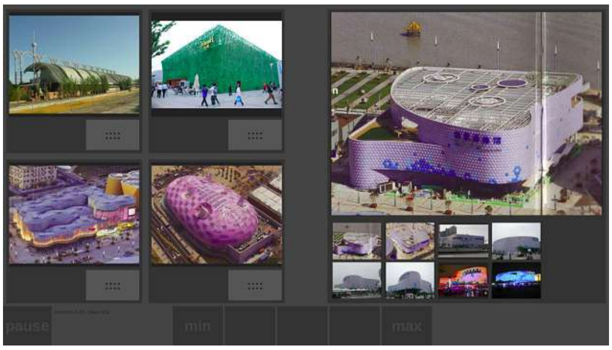
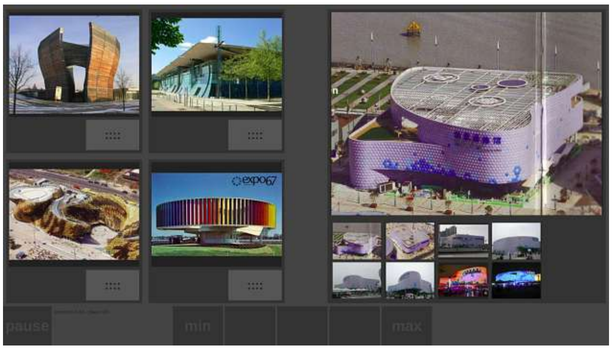


Plate H2ö

focus: **H2 - Info Communication**

top left: **H7 - Hungary**
top right: **G3 - Germany Host**
bottom left: **H5 - Spain**
bottom right: **E3 - Kaleidoscope**

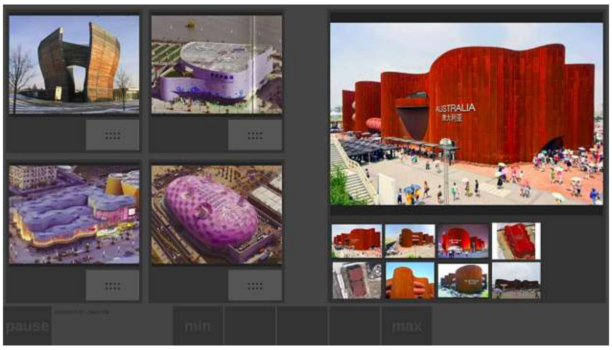


H3 - Expo 2010 Australia Pavilion (Shanghai)

group: **H - Undulation**
type: **Nation Pavilion**
prj-id: **prj2104**
emp-id: **emp-n-au10**

appears as focus in: **H3ä, H3ö, (see screenshots below)**
appears as compare in: **E2ö, E3ö, G1ü, G2ö, G3ö, H1ä, S3ü, X3ü,**
(also appears as focus in): **N8ä,**
(also appears as compare in): **H1â, J6ê, J9â, N1ä, N4ä,**

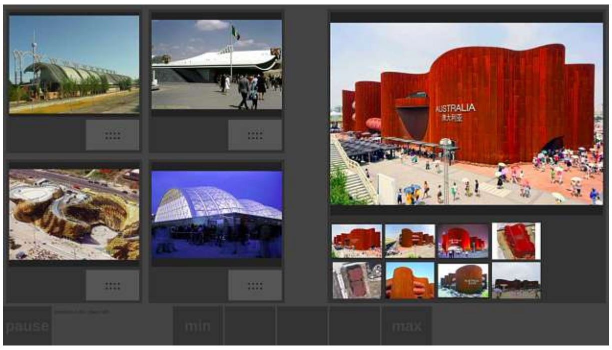
Plate H3ä



focus: **H3 - Australia (2010)**

top left: **H7 - Hungary**
top right: **H2 - Info Communication**
bottom left: **H4 - Private Enterprise**
bottom right: **F2 - Japan (2010)**

Plate H3ö



focus: **H3 - Australia (2010)**

top left: **H6 - Palaza Del Futuro**
top right: **G5 - Italy (1967)**
bottom left: **H5 - Spain**
bottom right: **F3 - Japan (2000)**

S1 - Expo 2010 France Pavilion (Shanghai)

group:	**S - Truncation Hole**	appears as focus in:	**S1ß, S1ä, (see screenshots below)**
type:	**Nation Pavilion**	appears as compare in:	**T1ä, U1ß, V1ä, X1ß,**
prj-id:	**prj2123**	(also appears as focus in):	**S1â,**
emp-id:	**emp-n-fr10**	(also appears as compare in):	**J3â, K2ö, K6ö,**

Plate S1ß

focus: **S1 - France (2010)**

top left: **Y1 - Denmark**
top right: **U1 - Netherlands (1967)**
bottom left: **G1 - Soviet Union (1967)**
bottom right: **C1 - Angola**

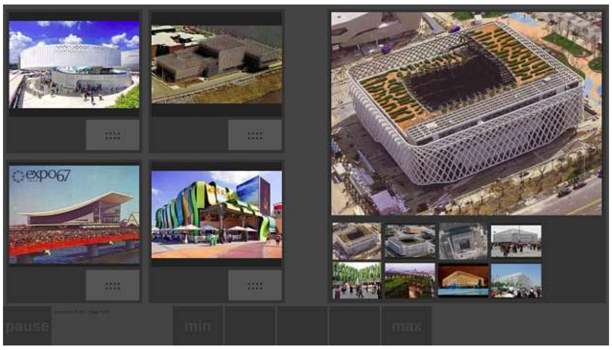
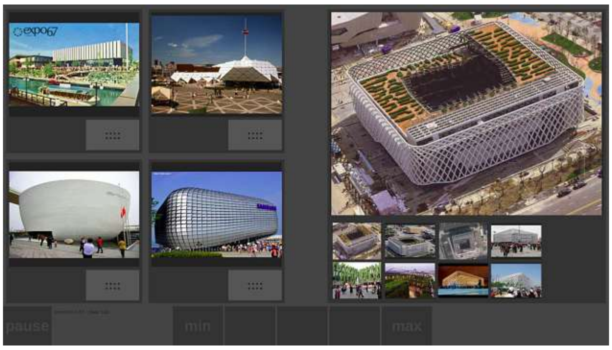


Plate S1ä

focus: **S1 - France (2010)**

top left: **S3 - Czechoslovakia**
top right: **V1 - Austria (1967)**
bottom left: **S2 - Finland**
bottom right: **T1 - Samsung**

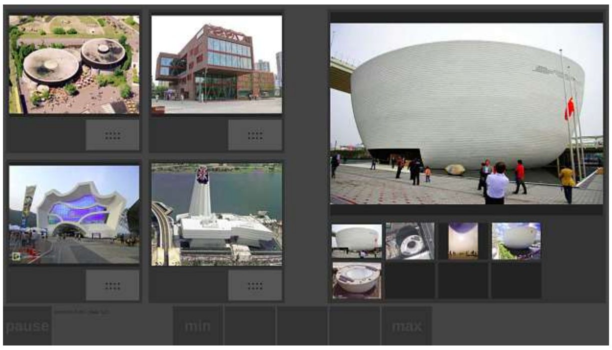


S2 - Expo 2010 Finland Pavilion (Shanghai)

group:	**S - Truncation Hole**	appears as focus in:	**S2ü, (see screenshots below)**
type:	**Nation Pavilion**	appears as compare in:	**S1ä, V2ü, Y2ü,**
prj-id:	**prj2122**	(also appears as focus in):	**J4â,**
emp-id:	**emp-n-fi**	(also appears as compare in):	**S1â, J9â, J9û, M1ö, M5ö,**

Plate S2ü

focus:	**S2 - Finland**
top left:	**X2 - Brewers**
top right:	**U2 - Hamburg**
bottom left:	**G2 - Hyundai**
bottom right:	**B2 - United Kingdom**



S3 - Expo 1967 Czechoslovakia Pavilion (Montreal)

group:	**S - Truncation Hole**	appears as focus in:	**S3ü, (see screenshots below)**
type:	**Nation Pavilion**	appears as compare in:	**S1ä, T3ü, Y3ü,**
prj-id:	**prj2406**	(also appears as focus in):	
emp-id:	**emp-n-cz**	(also appears as compare in):	**S1â, N2ö, N6ö,**

Plate S3ü

focus: **S3 - Czechoslovakia**

top left: **X3 - France (1970)**
top right: **V3 - Man The Explorer**
bottom left: **H3 - Australia (2010)**
bottom right: **B3 - Philippines**

T1 - Expo 2012 Samsunung Corporate Pavilion (Yeosu)

group:	**T - Truncation Corner**	appears as focus in:	**T1ß, T1ä, (see screenshots below)**
type:	**Corporate Pavilion**	appears as compare in:	**S1ä, U1ä, V1ß, W1ß,**
prj-id:	**prj3523**	(also appears as focus in):	**T1â,**
emp-id:	**emp-c-samsung**	(also appears as compare in):	**J6â, J9â, K2ö, K6ö,**

Plate T1ß

focus: **T1 - Samsung**

top left: **Z1 - Germany (1967)**
top right: **V1 - Austria (1967)**
bottom left: **H1 - Chile**
bottom right: **D1 - Ontario**

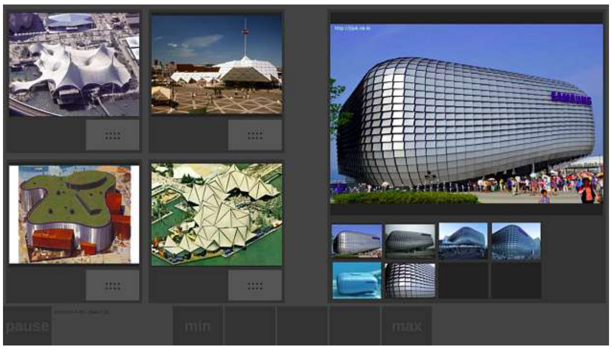
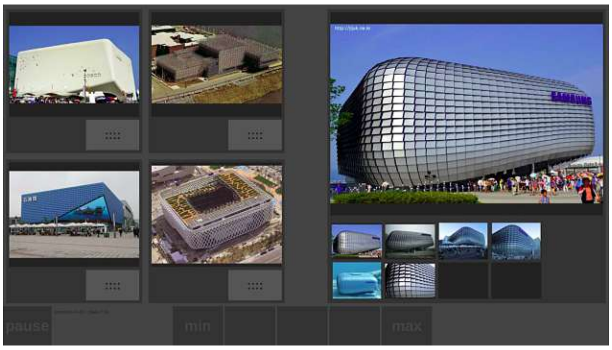


Plate T1ä

focus: **T1 - Samsung**

top left: **T3 - Posco**
top right: **U1 - Netherlands (1967)**
bottom left: **T2 - Oil**
bottom right: **S1 - France (2010)**



T2 - Expo 2010 Oil Corporate Pavilion (Shanghai)

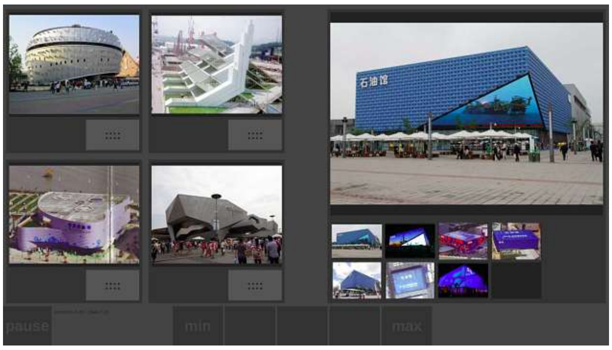
group: **T - Truncation**
Corner
type: **Corporate Pavilion**
prj-id: **prj2271**
emp-id: **emp-c-oil**

appears as focus in: **T2ü, (see screenshots below)**
appears as compare in: **T1ä, U2ü, Z2ü,**
(also appears as focus in):
(also appears as compare in): **T1â, M1ö, M5ö,**

Plate T2ü

focus: **T2 - Oil**

top left: **W2 - Singapore**
top right: **V2 - Italy (1970)**
bottom left: **H2 - Info Communication**
bottom right: **A2 - Germany (2010)**



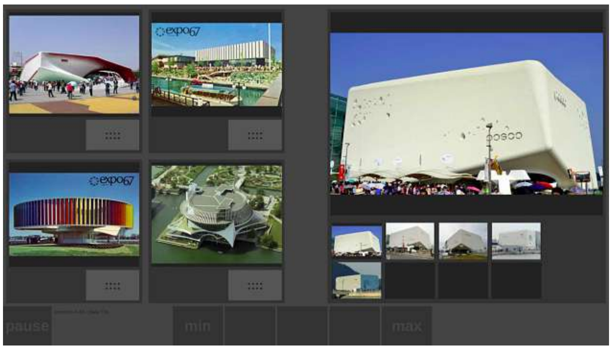
T3 - Expo 2012 Posco Corporate Pavilion (Yeosu)

group:	**T - Truncation Corner**	appears as focus in:	**T3ü, (see screenshots below)**
type:	**Corporate Pavilion**	appears as compare in:	**T1ä, U3ü, Z3ü,**
prj-id:	**prj2657**	(also appears as focus in):	
emp-id:	**emp-c-posco**	(also appears as compare in):	**T1â, N2ö, N6ö,**

Plate T3ü

focus: **T3 - Posco**

top left: **Y3 - Austria (2010)**
top right: **S3 - Czechoslovakia**
bottom left: **E3 - Kaleidoscope**
bottom right: **C3 - France (1967)**



U1 - Expo 1967 Netherlands Pavilion (Montreal)

group:	**U - Penetrate Boxes**	appears as focus in:	**U1ß, U1ä, (see screenshots below)**
type:	**Nation Pavilion**	appears as compare in:	**S1ß, T1ä, V1ä, Y1ß,**
prj-id:	**prj2426**	(also appears as focus in):	**U1â,**
emp-id:	**emp-n-nl67**	(also appears as compare in):	**J2ê, K2ö, K6ö,**

Plate U1ß

focus: **U1 - Netherlands (1967)**

top left: **W1 - Expo Culture Center**
top right: **S1 - France (2010)**
bottom left: **E1 - Canada (1967)**
bottom right: **A1 - Canada (2010)**

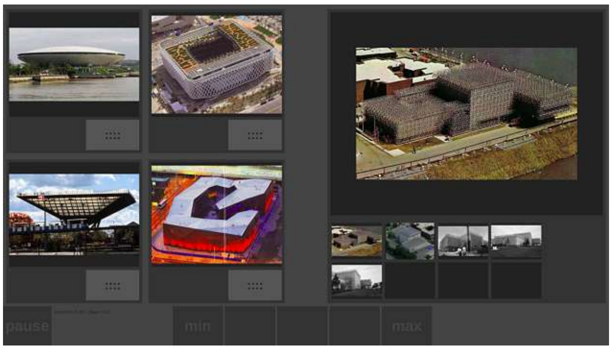
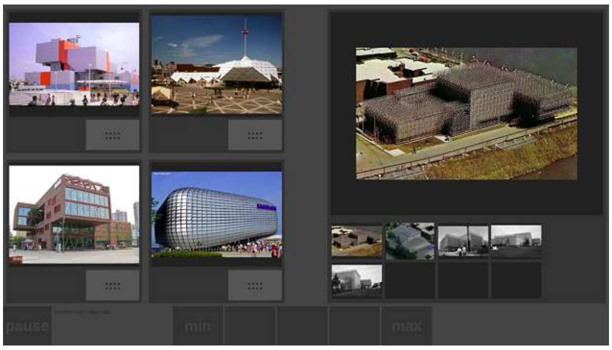


Plate U1ä

focus: **U1 - Netherlands (1967)**

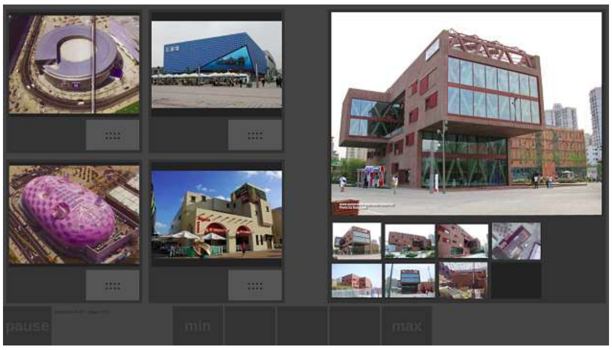
top left: **U3 - Netherlands (1970)**
top right: **V1 - Austria (1967)**
bottom left: **U2 - Hamburg**
bottom right: **T1 - Samsung**



U2 - Expo 2010 Hamburg Urban Pavilion (Shanghai)

group:	**U - Penetrate Boxes**	appears as focus in:	**U2ü, (see screenshots below)**
type:	**Urban Pavilion**	appears as compare in:	**S2ü, U1ä, X2ü,**
prj-id:	**prj2242**	(also appears as focus in):	
emp-id:	**emp-u-hamburg**	(also appears as compare in):	**U1â, J2ê, M1ö, M5ö,**

Plate U2ü



focus: **U2 - Hamburg**

top left: **Y2 - General Motors**
top right: **T2 - Oil**
bottom left: **F2 - Japan (2010)**
bottom right: **C2 - Algeria**

U3 - Expo 1970 Netherlands Pavilion (Osaka)

group:	**U - Penetrate Boxes**	appears as focus in:	**U3ü, (see screenshots below)**
type:	**Nation Pavilion**	appears as compare in:	**U1ä, V3ü, W3ü,**
prj-id:	**prj3128**	(also appears as focus in):	
emp-id:	**emp-n-nl70**	(also appears as compare in):	**U1â, J2ê, J9ê, N2ö, N6ö,**

Plate U3ü

focus: **U3 - Netherlands (1970)**

top left: **Z3 - Telecommunication**
top right: **T3 - Posco**
bottom left: **F3 - Japan (2000)**
bottom right: **D3 - Pulp and Paper**

V1 - Expo 1967 Austria Pavilion (Montreal)

group: **V - Geometry**
type: **Nation Pavilion**
prj-id: **prj2401**
emp-id: **emp-n-at67**

appears as focus in: **V1ß, V1ä, (see screenshots below)**
appears as compare in: **S1ä, T1ß, U1ä, Z1ß,**
(also appears as focus in): **V1â,**
(also appears as compare in): **J9ê, K2ö, K6ö,**

Plate V1ß

focus: **V1 - Austria (1967)**

top left: **X1 - Innovative Tours**
top right: **T1 - Samsung**
bottom left: **F1 - Fuji**
bottom right: **B1 - Soviet Union (1970)**

Plate V1ä

focus: **V1 - Austria (1967)**

top left: **V3 - Man The Explorer**
top right: **U1 - Netherlands (1967)**
bottom left: **V2 - Italy (1970)**
bottom right: **S1 - France (2010)**

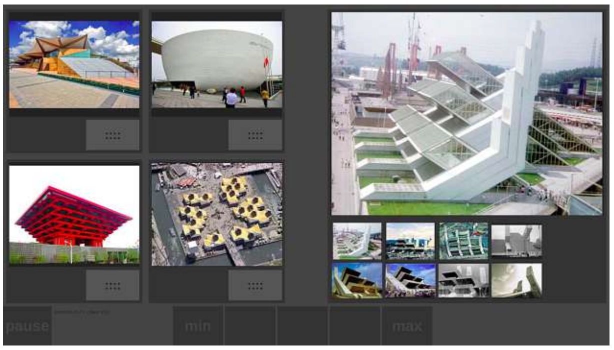
V2 - Expo 1970 Italy Pavilion (Osaka)

group:	**V - Geometry**	appears as focus in:	**V2ü, (see screenshots below)**
type:	**Nation Pavilion**	appears as compare in:	**T2ü, V1ä, W2ü,**
prj-id:	**prj3120**	(also appears as focus in):	
emp-id:	**emp-n-it70**	(also appears as compare in):	**V1â, J2ê, M1ö, M5ö,**

Plate V2ü

focus: **V2 - Italy (1970)**

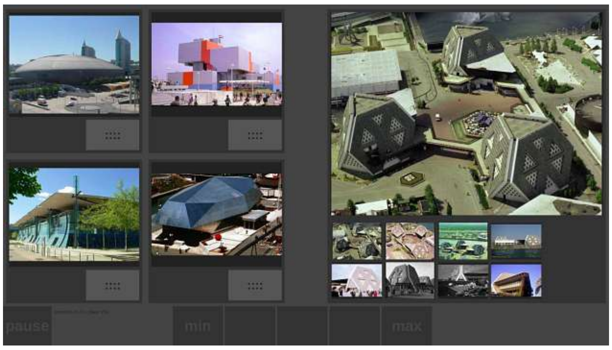
top left: **Z2 - Norway**
top right: **S2 - Finland**
bottom left: **E2 - China Host**
bottom right: **D2 - Africa**



V3 - Expo 1967 Man The Explorer Theme Pav. (Montreal)

group:	**V - Geometry**	appears as focus in:	**V3ü, (see screenshots below)**
type:	**Theme Pavilion**	appears as compare in:	**S3ü, V1ä, X3ü,**
prj-id:	**prj2529**	(also appears as focus in):	
emp-id:	**emp-t-explorer**	(also appears as compare in):	**V1â, N2ö, N6ö,**

Plate V3ü



focus:	**V3 - Man The Explorer**
top left:	**W3 - Pavilion Of The Future**
top right:	**U3 - Netherlands (1970)**
bottom left:	**G3 - Germany Host**
bottom right:	**A3 - Europe**

W1 - Expo 2010 Expo Culture Center Host Pav. (Shanghai)

group:	**W - Ufo**	appears as focus in:	**W1ß, W1ä, (see screenshots below)**
type:	**Host Building**	appears as compare in:	**U1ß, X1ä, Y1ä, Z1ß,**
prj-id:	**prj2003**	(also appears as focus in):	**W1â, J9û,**
emp-id:	**emp-host-culture**	(also appears as compare in):	**K3ü, K7ü,**

Plate W1ß

focus: **W1 - Expo Culture Center**

top left: **Y1 - Denmark**
top right: **T1 - Samsung**
bottom left: **F1 - Fuji**
bottom right: **C1 - Angola**

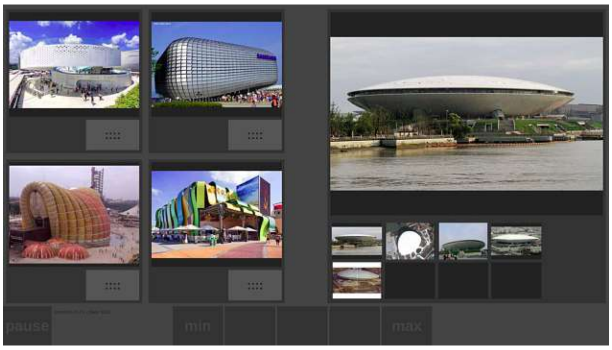
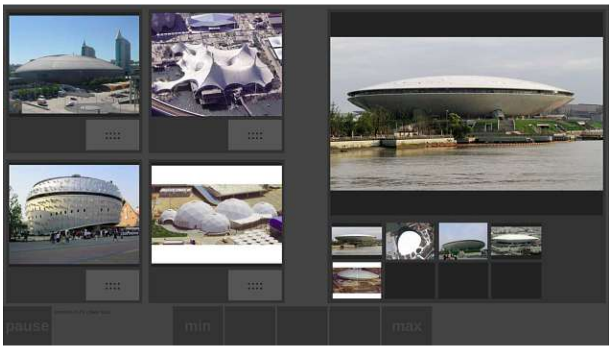


Plate W1ä

focus: **W1 - Expo Culture Center**

top left: **W3 - Pavilion Of The Future**
top right: **Z1 - Germany (1967)**
bottom left: **W2 - Singapore**
bottom right: **X1 - Innovative Tours**



W2 - Expo 2010 Singapore Pavilion (Shanghai)

group: **W - Ufo**
type: **Nation Pavilion**
prj-id: **prj2166**
emp-id: **emp-n-sg**

appears as focus in: **W2ü, (see screenshots below)**
appears as compare in: **T2ü, W1ä, Z2ü,**
(also appears as focus in):
(also appears as compare in): **W1â, J4â, J8â, M4ü, M8ü,**

Plate W2ü

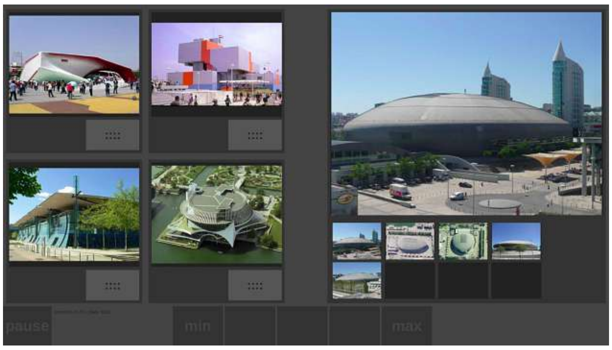
focus: **W2 - Singapore**

top left: **Y2 - General Motors**
top right: **V2 - Italy (1970)**
bottom left: **H2 - Info Communication**
bottom right: **C2 - Algeria**

W3 - Expo 1998 Pav. of the Future Theme Pavilion (Lisboa)

group:	**W - Ufo**	appears as focus in:	**W3ü, (see screenshots below)**
type:	**Theme Pavilion**	appears as compare in:	**V3ü, W1ä, Y3ü,**
prj-id:	**prj2731**	(also appears as focus in):	
emp-id:	**emp-t-future**	(also appears as compare in):	**W1â, J4â, J8ê, N3ü, N7ü,**

Plate W3ü

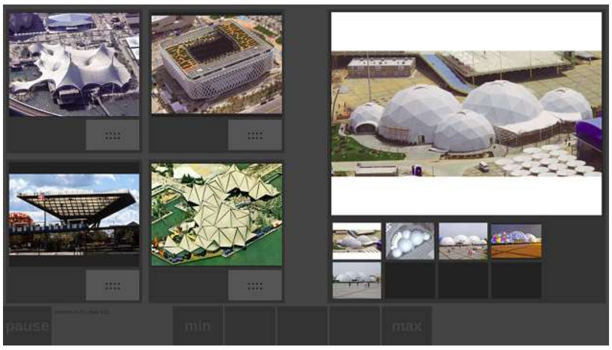


focus:	**W3 - Pavilion Of The Future**
top left:	**Y3 - Austria (2010)**
top right:	**U3 - Netherlands (1970)**
bottom left:	**G3 - Germany Host**
bottom right:	**C3 - France (1967)**

X1 - Expo 2010 Innovative Tours Theme Pavilion (Shanghai)

group:	**X - Bubbles**	appears as focus in:	**X1ß, X1ä, (see screenshots below)**
type:	**Theme Pavilion**	appears as compare in:	**V1ß, W1ä, Y1ß, Z1ä,**
prj-id:	**prj2229**	(also appears as focus in):	**X1â,**
emp-id:	**emp-t-tours**	(also appears as compare in):	**J6â, K3ü, K7ü,**

Plate X1ß



focus:	**X1 - Innovative Tours**
top left:	**Z1 - Germany (1967)**
top right:	**S1 - France (2010)**
bottom left:	**E1 - Canada (1967)**
bottom right:	**D1 - Ontario**

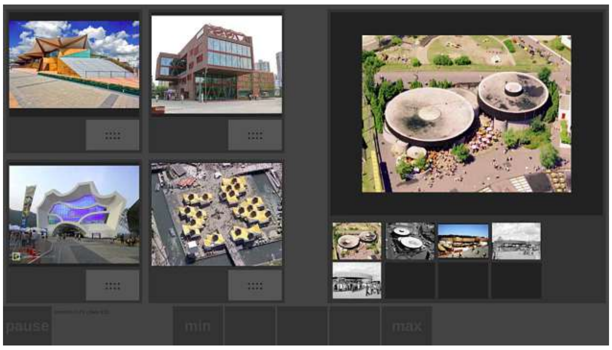
Plate X1ä

focus:	**X1 - Innovative Tours**
top left:	**X3 - France (1970)**
top right:	**Y1 - Denmark**
bottom left:	**X2 - Brewers**
bottom right:	**W1 - Expo Culture Center**

X2 - Expo 1967 Brewers Pavilion (Montreal)

group:	**X - Bubbles**	appears as focus in:	**X2ü, (see screenshots below)**
type:	**Corporate Pavilion**	appears as compare in:	**S2ü, X1ä, Y2ü,**
prj-id:	**prj2562**	(also appears as focus in):	
emp-id:	**emp-c-brewers**	(also appears as compare in):	**X1â, J8â, M4ü, M8ü,**

Plate X2ü



focus:	**X2 - Brewers**
top left:	**Z2 - Norway**
top right:	**U2 - Hamburg**
bottom left:	**G2 - Hyundai**
bottom right:	**D2 - Africa**

X3 - Expo 1970 France Pavilion (Osaka)

group:	**X - Bubbles**	appears as focus in:	**X3ü, (see screenshots below)**
type:	**Nation Pavilion**	appears as compare in:	**S3ü, X1ä, Z3ü,**
prj-id:	**prj3117**	(also appears as focus in):	
emp-id:	**emp-n-fr70**	(also appears as compare in):	**X1â, J6â, N3ü, N7ü,**

Plate X3ü

focus: **X3 - France (1970)**

top left: **Z3 - Telecommunication**
top right: **V3 - Man The Explorer**
bottom left: **H3 - Australia (2010)**
bottom right: **D3 - Pulp and Paper**

Y1 - Expo 2010 Denmark Pavilion (Shanghai)

group:	**Y - Spiral**	appears as focus in:	**Y1ß, Y1ä, (see screenshots below)**
type:	**Nation Pavilion**	appears as compare in:	**S1ß, W1ß, X1ä, Z1ä,**
prj-id:	**prj2117**	(also appears as focus in):	**Y1â, J3â, J3ê,**
emp-id:	**emp-n-dk**	(also appears as compare in):	**K3ü, K7ü,**

Plate Y1ß

focus: **Y1 - Denmark**

top left: **X1 - Innovative Tours**
top right: **U1 - Netherlands (1967)**
bottom left: **G1 - Soviet Union (1967)**
bottom right: **B1 - Soviet Union (1970)**

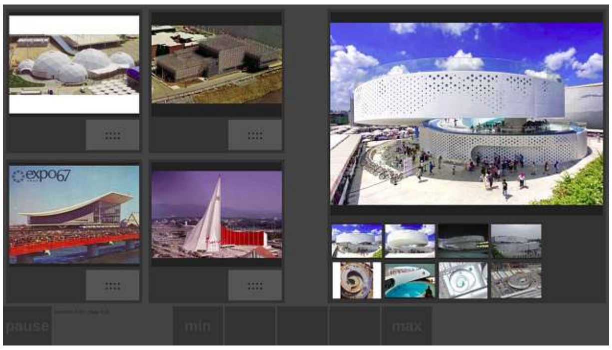
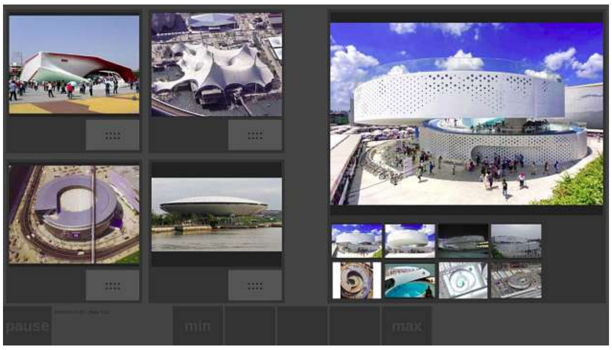


Plate Y1ä

focus: **Y1 - Denmark**

top left: **Y3 - Austria (2010)**
top right: **Z1 - Germany (1967)**
bottom left: **Y2 - General Motors**
bottom right: **W1 - Expo Culture Center**



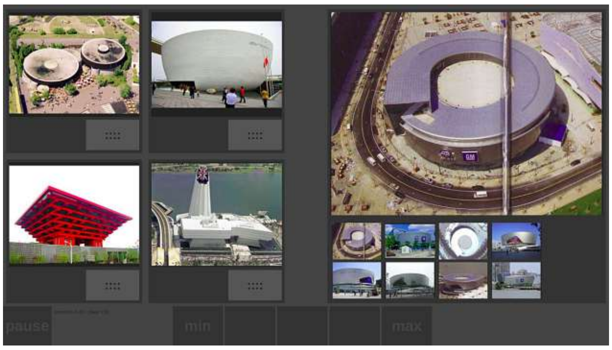
Y2 - Expo 2010 General Motors Corporate Pav. (Shanghai)

group:	**Y - Spiral**	appears as focus in:	**Y2ü, (see screenshots below)**
type:	**Corporate Pavilion**	appears as compare in:	**U2ü, W2ü, Y1ä,**
prj-id:	**prj2267**	(also appears as focus in):	
emp-id:	**emp-c-gm**	(also appears as compare in):	**Y1â, J8â, M4ü, M8ü,**

Plate Y2ü

focus: **Y2 - General Motors**

top left: **X2 - Brewers**
top right: **S2 - Finland**
bottom left: **E2 - China Host**
bottom right: **B2 - United Kingdom**



Y3 - Expo 2010 Austria Pavilion (Shanghai)

group: **Y - Spiral**
type: **Nation Pavilion**
prj-id: **prj2103**
emp-id: **emp-n-at10**

appears as focus in: **Y3ü, (see screenshots below)**
appears as compare in: **T3ü, W3ü, Y1ä,**
(also appears as focus in):
(also appears as compare in): **Y1â, N3ü, N7ü,**

Plate Y3ü

focus: **Y3 - Austria (2010)**

top left: **W3 - Pavilion Of The Future**
top right: **S3 - Czechoslovakia**
bottom left: **E3 - Kaleidoscope**
bottom right: **A3 - Europe**

Z1 - Expo 1967 Germany Pavilion (Montreal)

group: **Z - Anticlastic**
type: **Nation Pavilion**
prj-id: **prj2407**
emp-id: **emp-n-de67**

appears as focus in: **Z1ß, Z1ä, (see screenshots below)**
appears as compare in: **T1ß, W1ä, X1ß, Y1ä,**
(also appears as focus in): **Z1â,**
(also appears as compare in): **J5â, K3ü, K7ü,**

Plate Z1ß

focus: **Z1 - Germany (1967)**

top left: **W1 - Expo Culture Center**
top right: **V1 - Austria (1967)**
bottom left: **H1 - Chile**
bottom right: **A1 - Canada (2010)**

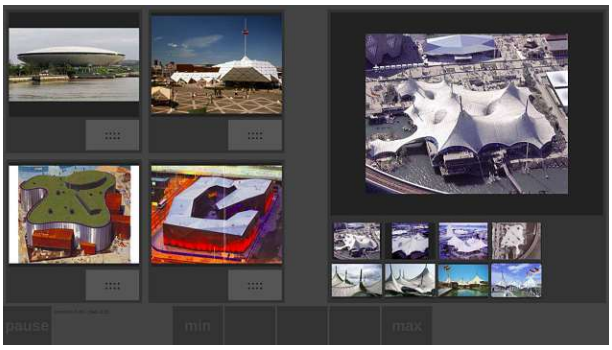
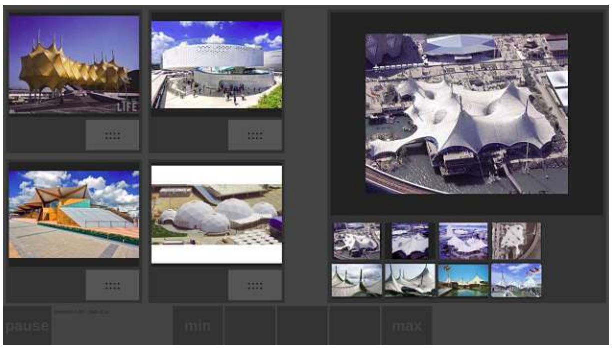


Plate Z1ä

focus: **Z1 - Germany (1967)**

top left: **Z3 - Telecommunication**
top right: **Y1 - Denmark**
bottom left: **Z2 - Norway**
bottom right: **X1 - Innovative Tours**



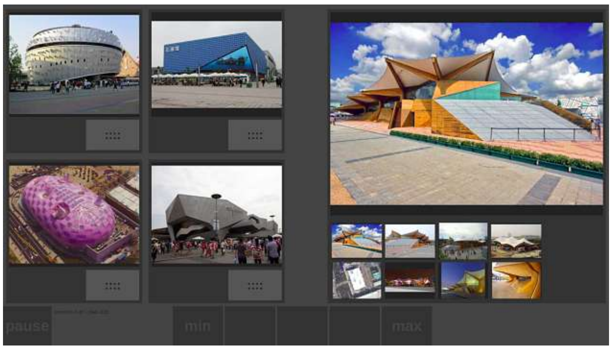
Z2 - Expo 2010 Norway Pavilion (Shanghai)

group:	**Z - Anticlastic**	appears as focus in:	**Z2ü, (see screenshots below)**
type:	**Nation Pavilion**	appears as compare in:	**V2ü, X2ü, Z1ä,**
prj-id:	**prj2151**	(also appears as focus in):	
emp-id:	**emp-n-no**	(also appears as compare in):	**Z1â, J5â, M4ü, M8ü,**

Plate Z2ü

focus: **Z2 - Norway**

top left: **W2 - Singapore**
top right: **T2 - Oil**
bottom left: **F2 - Japan (2010)**
bottom right: **A2 - Germany (2010)**



Z3 - Expo 1970 Telecommunication Corporate Pav. (Osaka)

group:	**Z - Anticlastic**	appears as focus in:	**Z3ü, (see screenshots below)**
type:	**Corporate Pavilion**	appears as compare in:	**U3ü, X3ü, Z1ä,**
prj-id:	**prj3261**	(also appears as focus in):	
emp-id:	**emp-c-tele**	(also appears as compare in):	**Z1â, N3ü, N7ü,**

Plate Z3ü

focus: **Z3 - Telecommunication**

top left: **X3 - France (1970)**
top right: **T3 - Posco**
bottom left: **F3 - Japan (2000)**
bottom right: **B3 - Philippines**

1. Grid

The following pages document how the data gathering screens are created.

The grid in Figure 1 was composed to assemble screens in a consistent way. There are four group of screens: “A,B,C,D”, “E,F,G,H”, “S,T,U,V”, “W,X,Y,Z”. Screens within one group like “A,B,C,D” only consist of pavilions from the same group. Therefore there is no immediate interconnection between the major blocks in the strict canonical part of the screens. The canonical screens are the ones which have been taken as the base of the calculations. Though additional screens have been added to keep fast participants busy (see end of Appendix D). Fast participants also were shown the canonical screens twice.

This design was taken deliberately to allow future research to add additional bigger groups like “I,J,K,L”. It is also possible to expand the small groups like “S1, S2, S3” with more examples to have seven members as well. (the greyed out parts). A purely random path for a participant of all the screens would make the extension much harder. As all existing pavilions would be interweave and new pavilions would not have the same connectivity.

Each vertical column in Figure 1 and Figure 2, like the first one: A1ä, A1ö, A1ü, A2ä, A2ö, A3ä, A3ö shows all screens for one curated group.

- The curated group A is colour coded in green.
- Other “1” pavilions like B1, C1, D1 are colour code blue
- Other “2” and “3” pavilions like B2 or B3 are colour coded orange
- Gap filling pavilions are colour coded magenta. They come from “4” and “5”

The 52 participants have been randomly assigned a *tour* which is the order in which a participants sees slides. A *tour* is a group of *tracks*. A *track* is a group of screens. The grouping of screens within a track tries to achieve a data objective like “most-of-ABCD, 1ä-of-EFGH, 1ä-of-STUV”.

There are two major tours for the participants. Approximately half of the participants started a with a focus on “A,B,C,D” before moving the focus to “E,F,G,H”. The other half of the participants did the opposite.

Full details about participants, their tours and path are available in a JSON data format. Also a lot of additional data points like time spend on a photograph, and timing to complete a screen is available, but was not used directly in the main thesis.

Figure 1: Grid to compose data gathering screens in a consistent way

Figure 2: Example of all pavilions in the column: A1ä, A1ö, A1ü, A2ä, A2ö, A3ä, A3ö

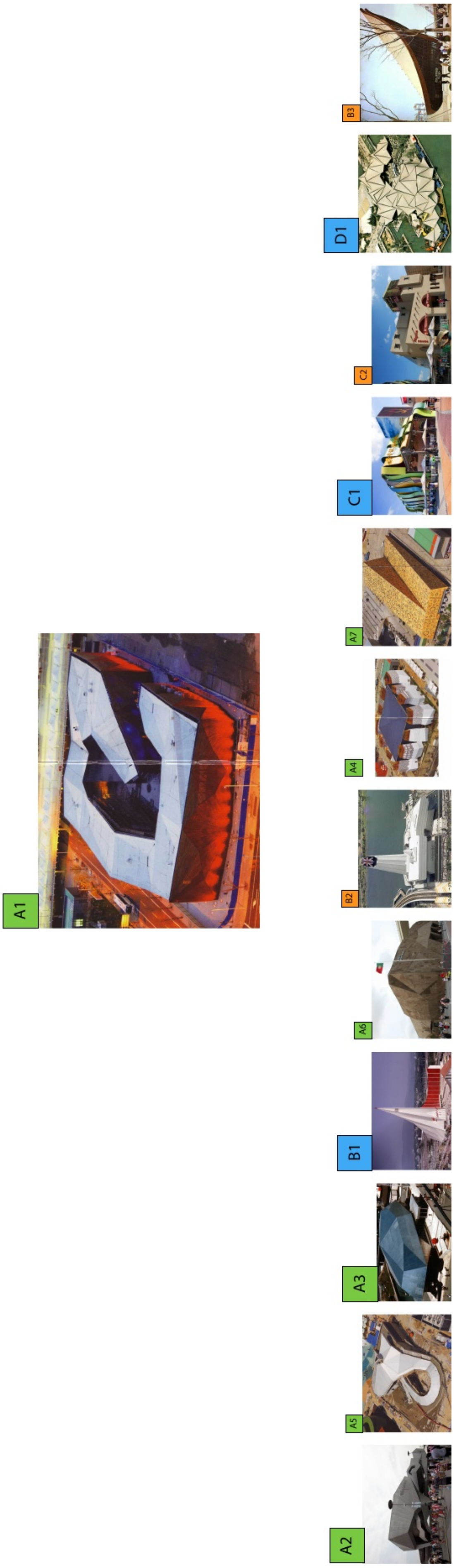


Figure 3: All pavilions which have been compared to A1

Additional plates that have been used to keep fast participants busy and extract interesting (curated) information are documented in a brief text format.

J - This is an additional fast-track for session B onwards with xCrossCutting;

```
J1â:     focus: D4     compare: E2, E3, E4, H4
J2â:     focus: E7     compare: E5, D5, D6, C2
J2ê:     focus: E7     compare: U1, U2, U3, V2
J3â:     focus: Y1     compare: C3, A7, S1, D6
J3ê:     focus: Y1     compare: A1, A5, C5, B1
J4â:     focus: S2     compare: W2, H7, C3, W3
J5â:     focus: B7     compare: Z1, Z2, D1, B4
J6â:     focus: F3     compare: T1, X1, X3, F6
J6ê:     focus: F3     compare: F2, H3, H4, H6
J7â:     focus: B1     compare: A2, A3, A6, A7
J7ê:     focus: B5     compare: A1, A2, A5, D3
J8â:     focus: E3     compare: X2, W2, Y2, H4
J8ê:     focus: E4     compare: F2, F1, F7, W3
J9â:     focus: F1     compare: T1, C5, H3, S2
J9ê:     focus: D2     compare: V1, U3, A4, H4
J9û:     focus: W1     compare: S2, E4, C3, E3
```

K - This is an additional fast-track for session B onwards. XconnectMoreK:

```
K1ä:     focus: A1     compare: E1, F1, G1, H1
K2ö:     focus: B1     compare: S1, T1, U1, V1
K3ü:     focus: C1     compare: W1, X1, Y1, Z1
K4ä:     focus: D1     compare: E1, F1, G1, H1
K5ä:     focus: E1     compare: A1, B1, C1, D1
K6ö:     focus: F1     compare: S1, T1, U1, V1
K7ü:     focus: G1     compare: W1, X1, Y1, Z1
K8ä:     focus: H1     compare: A1, B1, C1, D1
```

M - This is an additional fast-track for session D onwards. XconnectMoreM:

```
M1ö:     focus: A2     compare: S2, T2, U2, V2
M2ä:     focus: B2     compare: E2, F2, G2, H2
M3ä:     focus: C2     compare: E2, F2, G2, H2
M4ü:     focus: D2     compare: W2, X2, Y2, Z2
M5ö:     focus: E2     compare: S2, T2, U2, V2
M6ä:     focus: F2     compare: A2, B2, C2, D2
M7ä:     focus: G2     compare: A2, B2, C2, D2
M8ü:     focus: H2     compare: W2, X2, Y2, Z2
```

N - This is an additional fast-track for session D onwards. xConnectMoreN. This is similar to xConnectMoreK because I want a tight connection between ABCDEFGH:

```
N1ä:     focus: A3     compare: E3, F3, G3, H3
N2ö:     focus: B3     compare: S3, T3, U3, V3
N3ü:     focus: C3     compare: W3, X3, Y3, Z3
N4ä:     focus: D3     compare: E3, F3, G3, H3
N5ä:     focus: E3     compare: A3, B3, C3, D3
N6ö:     focus: F3     compare: S3, T3, U3, V3
N7ü:     focus: G3     compare: W3, X3, Y3, Z3
N8ä:     focus: H3     compare: A3, B3, C3, D3
```

This page intentionally left blank in print layout

This page intentionally left blank in print layout

Appendix E

Software Implementation

part of doctoral thesis

Building Shape Classification

Philipp Jurewicz 2023

Table of Contents

1. Introduction

This Appendix documents the software implementation that was developed alongside the theory part of Building Shape Classification.

The author is in the fortunate position to be able to write the full software implementation by himself. He currently works as a professional software engineer, but has his educational background in architecture. The topic of building shape classification is mainly a *subject matter challenge*. Though it is also a *software engineering task*. The software handles classification with a custom data structure and visualisation. Writing software is a time intensive but rewarding task, as one can see a theory become executable and verifiable.

To give an indication about the quantity of work done in the software implementation we can measure *Lines of Code* (LoC).[1] This metric sums up all lines written in the Java and Groovy programming languages used in the *backend* of this project[2]. Overall source code: 35822 LoC; Subset main source code: 21660 LoC; Subset unit test code: 14162 LoC.

The software evolved during the time the theory was written. The software implementation covers several requirements, which coincide with different time periods:

Time period: Early in the research:

- Digitalising the thought model.
  Goal: To assist the author to carve out the theoretical data structures: Building Shape Syntax Tree, Periphrase, Classification Sets, and Weak References.
- Visualising Building Shape Syntax Trees.
  Goal: To assist the author to have a rough two dimensional representation of the data model, which is one of the innovations of the theory.

Time period: Empirical data gathering:

- Interactive plates for the empirical data gathering
  Goal: To have a web application that serve an interactive user interface to the 52 participants for the empirical data gathering.

Time period: Verification of the theory with the empirical data:

1 The following Regular Expression was used to get the metric of *Lines of Code*:
`^(?![ \s]*\r?\n|import|package|[ \s]*}\r?\n|[ \s]*//|[ \s]*/\*|[ \s]*\*).*\r?\n`
It omits: Blank lines; Imports; Line with the name package; Lines with just a }; Lines with comments.

2 This metric even excludes the visualisations written in HTML, CSS and JavaScript in the *frontend* of the project.

- Joining calculated and empirical data.
  Goal: Verification of the theory with the empirical data. Assist the author to verify if the theory and its software implementation produces meaningful data.

- Visualising calculated and empirical together.
  Goal: Understand and interactively deep dive into the results.

Time period: Finishing:

- Automated Print Quality Visualisation.
  Goal: Assist the author to add statistical tables and multiple generated Appendices.

- Exploring Structural Design Aid (SDA); a small helper project.
  Goal: Assist the author to better understand structural data of the SDA database to finish chapter 5.4.3

The software is assembled in several modules. Most of the modules coincide with one of four time periods, but some modules catered multiple tasks during the life cycle.

2. Technology

2.1. Software Architecture

All modules have been developed as web server applications. While some modules serve mostly technical data in XML or JSON format, other modules consume this data and perform calculation or visualise it to the user. This kind of loosely coupled system is commonly refereed to as a *Microservice Architecture*. Distributes Microservices have many advantages in scaling to huge amounts of requests and a development model which allows dozens of people to contribute source code for the same goal. While important for the software industry, *scale* and *team size* are not the reason why the software architecture was chosen by the author. An additional strength of Microservice Architecture is, that it allows Domain Driven Design (DDD). The same concept might have slightly different meanings in different parts of the whole software project – domains – and having separate modules allows the software to evolve within given boundaries without effecting other parts all the time. Though, at the end the modules have to interact with each other and produce meaningful outputs together.

Many software projects have a traditional relational database as its main persistence technology. This is not the case for this software. It loads the data either on server startup or on demand purely from the file system. XML and JSON files serve as the persistence. This is acceptable because the amount of data is not challenging for contemporary hardware of a computer notebook. We have 80 World Exposition data models and a few ten thousand statistical data point. The data is enriched during the loading, aggregated when needed and kept in-memory. This means that there are no breaks or in-revertible milestones in the software. Producing a diagram for an Appendix, a day before this doctoral thesis goes into print as a PDF, parses the whole original empirical data again.

The software client to interact with the software as a human is a web browser. Because of browser technology choices and the audience of either a single user – the author – or a small group of participants that use devices controlled by the author, there is only one fully supported web browser engine. At the time of this doctoral thesis the Google Chrome and its sibling open source Chromium were the best choices to support the requirements. This was mainly driven by the ability to support browser native *Web Components* and predictable print quality PDF output. Mozilla Firefox served as a secondary browser and the main choice of the author to access the Internet.

Software is written in programming languages. The backend of the software was written in the Java programming language. Small parts of the backend are also written in the

Groovy programming language. The Groovy programming language uses the same runtime as Java: the Java Virtual Machine (JVM). The frontend which runs in the web browser uses JavaScript as its programming language. The data interchange formats are XML and JSON.

In the Java and JavaScript community *Open Source Software* (OSS) is a foundation for many task. The server backend is written with the Spring Boot stack. The build tool is Gradle. The frontend utilises the *Web Component* library Polymer. The Polymer library itself is discontinued by its corporate sponsor Google but the official successor library "lit-html" evolves the idea of Web Components further.

2.2. Interface Periphrase to Syntax Tree

Many scientific software projects have a valuable or novel software algorithm at its core. The author does not claim to have invented such a novel algorithm for this doctoral thesis. It is not a computer science doctoral thesis, but rather a *software supported* domain thesis. Most of the software tasks at hand were craftsmanship tasks. Similar to the day to day job of a senior software developer in a commercial setting.

Still there is one place where the software does contribute an important part. It automates a tedious procedure to make batch comparison of buildings possible.

The task is documented in chapter 9 of the main document. Subchapter 9.7 documents the *bubble-up* phase and the *rules* with their behaviour and numerical constant values. The rules are simple in their software implementation, and the documentation in the main document should be sufficient. Though, we will explain the essential interface between the Periphrase and the Syntax Tree in this Appendix in more technical terms then in the main document chapter 9.6.

When we compute the numeric similarity value of two buildings we take one building as the *Focus* and the other as the *Candidate*. The data structures are XML trees, which can be loaded into two Document Object Models (DOM) in Java on the backend. The two DOM models can be inspected at the same time. In theory both, the *Focus* can have n multiple Periphrases, as well as the *Candidate* can have m multiple Periphrases. We have a matrix of n by m elements. As an example, we can think of a matrix like 3 by 3 elements. At the interface between Syntax Tree and Periphrase the software has to decide which *Candidate Periphrase* has to be associated with which *Focus Periphrase*.

Before we describe the special treatment of the permutation at the interface level, we describe a permutation at the Syntax Tree level. This is useful because the value from the interface finally contributes at the Syntax Tree permutation. The same rules and source code is used in both cases.

The similar permutation happens for competing classification items that bubble up the Syntax Tree. We can think of two *competing* classification items for the *Spacing* classification set. The one that contributes most, at the root of the tree is picked. Even if both Focus and Candidate have just a single Spacing slot, there are multiple values to compete against each other. These values come from the Weak References list (see Appendix B). In simple cases the value with the highest initial score is also the one that contributes most at the root of the Syntax Tree.

In case multiple classification items for Spacing appear in the Focus as well as the Candidate the best combination is picked. The best combination is not necessary the obvious one. This is fuelled by the flexibility of Weak References. For instance a combination of 100 and 10, might be outperformed by a combination of 50 and 50.

Lets return to the permutation at the interface level.

At the interface, the data structure of a Periphrase is reduced to a single numerical value. The numerical value is then placed at a placeholder leaf in the Focus Syntax Tree. Then this value contributes in the bubble up phase of the Syntax Tree similar to a sibling leaf that represent a classification item like Spacing. Together all bubbled up values that are transformed by the rules add up to the similarity value. Therefore it is desirable to have the top performing combination picked at the interface.

The interface achieves this by iterating of all possible permutations. For a 3 by 3 matrix these are 3 x 2 x 1 = 6 permutations. It takes each possible combination and performs the whole Syntax Tree calculation for it. The best performing combination is then picked and all other dropped.

But there is a special subject that the interface level permutation must obey. The values in the placeholder Periphrase slots alter the inputs that are required for the calculation of the "*push-multiplier*" which results form the *rule of composition composition push* (see main document chapter 9.7.3). Therefore the permutation also recalculated the *push-multiplier* each time. The best combination is not necessary the obvious one. This is fuelled by the flexibility of the *push-multiplier*. In theory a combination of 100 and 10, might be outperformed by a combination of 50 and 50.

This outperforming effect is mostly relevant when there is an asymmetry between the number of Periphrases in the Focus and Candidate. We can think of 4 Periphrases of the Candidate competing for the 2 Periphrases slots that the Focus offers.

2.3. Pragmatic Rule and Scoring Values

Chapter 9 of the main document contains multiple tables. The numbers in these tables are easy to follow: "100 points to start with", "90% penality", "20% penality". While the numbers are strictly speaking arbitrary picked human readable values, they roughly follow a sine curve, or a Gaussian distribution curve; but only roughly. It would be possible to have closer matches to numbers calculated from a sine function, but it would make the task to develop this thesis very hard. During the first phase of the software the author looked at the numbers bubbling up on the Syntax Tree in the web browser to verify that the rules are useful in the first place. Having decimal values would have made this task harder. Also the author inspected multiple of the same comparisons that have been part of 352 pairs that are part of the empirical data gatherings (see Appendix D).

We can assume that these are not the optimal numbers. Future implementation could alter the values. When more model data and empirical data would be available it could be possible to let a computer program calculate the optimal values. Unfortunately this is out of scope for this thesis.

There are different valid approaches to make these numbers *less arbitrary*.

- One method would be to balance the numbers of the initial values on a *per comparison pair* base. This would mean that a different comparison pair, would have different numbers to start with. This would be even true when one of the members of the pair is the same as before. Human inspection would be harder.
- Another approach would be to calculate the initial numbers on a *per collection* base. This would mean that on the calculated side we could permute the 80 x 79 x 78 ... examples and find the values that perform best. Each new building added to the collection would alter these values.
- When we take the empirical setup as the base, it would be the average values from the 88 plates with their in sum 354 comparison. But then the system would be solely focused to match the empirical data, rather then being more generic.
- Other statistical approaches and trends like Machine Learning could calculated better values for the system. But as mentioned multiple times in the doctoral thesis; the subject matter of Building Shape does not have sources with enough quantity of good data. At least not known to the author.

The current workaround is that we translate the score values to percent values. These makes the comparison pairs as well as the whole system comparable. The idea of simple scoring is not uncommon in important software projects like the open source search engine Lucene or applied Bayesian models.

2.4. Screenshots of Additional Custom Tailored Tools

The software implementation performs the *calculation heavy comparison* of pairs of pavilions, as well as the *aggregation* of the batch data of the 80 World Exposition pavilions. This is a *behind the scenes* tasks were visual output is only secondary.

Additionally custom developed software by the author was also used in a lot of stages for *visualization* of the data:

- The empirical data gathering application. See chapter 11.2. and Appendix D
- The main parts of Appendix A, B, C and D are generated from data.
- The tables in chapter 12.1 are generated from data
- Generated colour coded tables are the bases for the visualisations in chapter 12.2 and 12.4 in Tables 38, 39, 40, 41, 42, and Figures 339, 340, 341.

This section additionally documents with a few screenshots some custom developed software tools which are not depicted in main document or the Appendices. All tools are web browser applications. The following pages will show screenshots from:

- The early Syntax Tree visualisations.
- The quality assurance tool for reviewing the gathered empirical data.
- An interactive application to see calculated and empirical data side by side.
- A filterable and sortable pivot table to explore the own data set.
- A filterable and sortable pivot table to explore the Structural Design Aid (SDA) data.

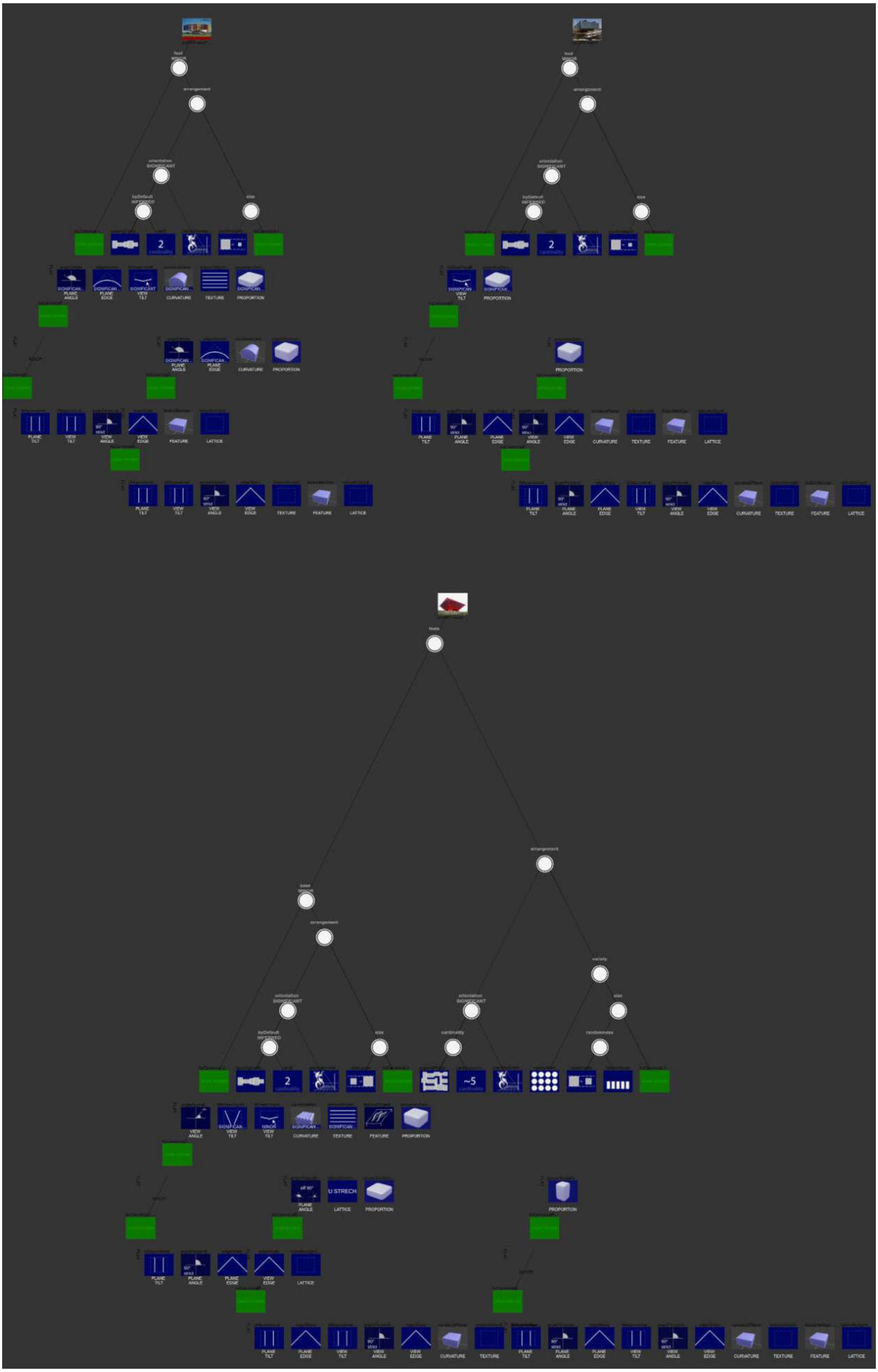


Figure 1: Impression of three Syntax Trees. It is an interactive web based HTML application which allows to toggle visibility of various branches. Top left: E3 Kaleidoscope ; Top right: E6 Quebec Pavilion;
Bottom: E2 - Expo 2010 China Host Pavilion (Shanghai)

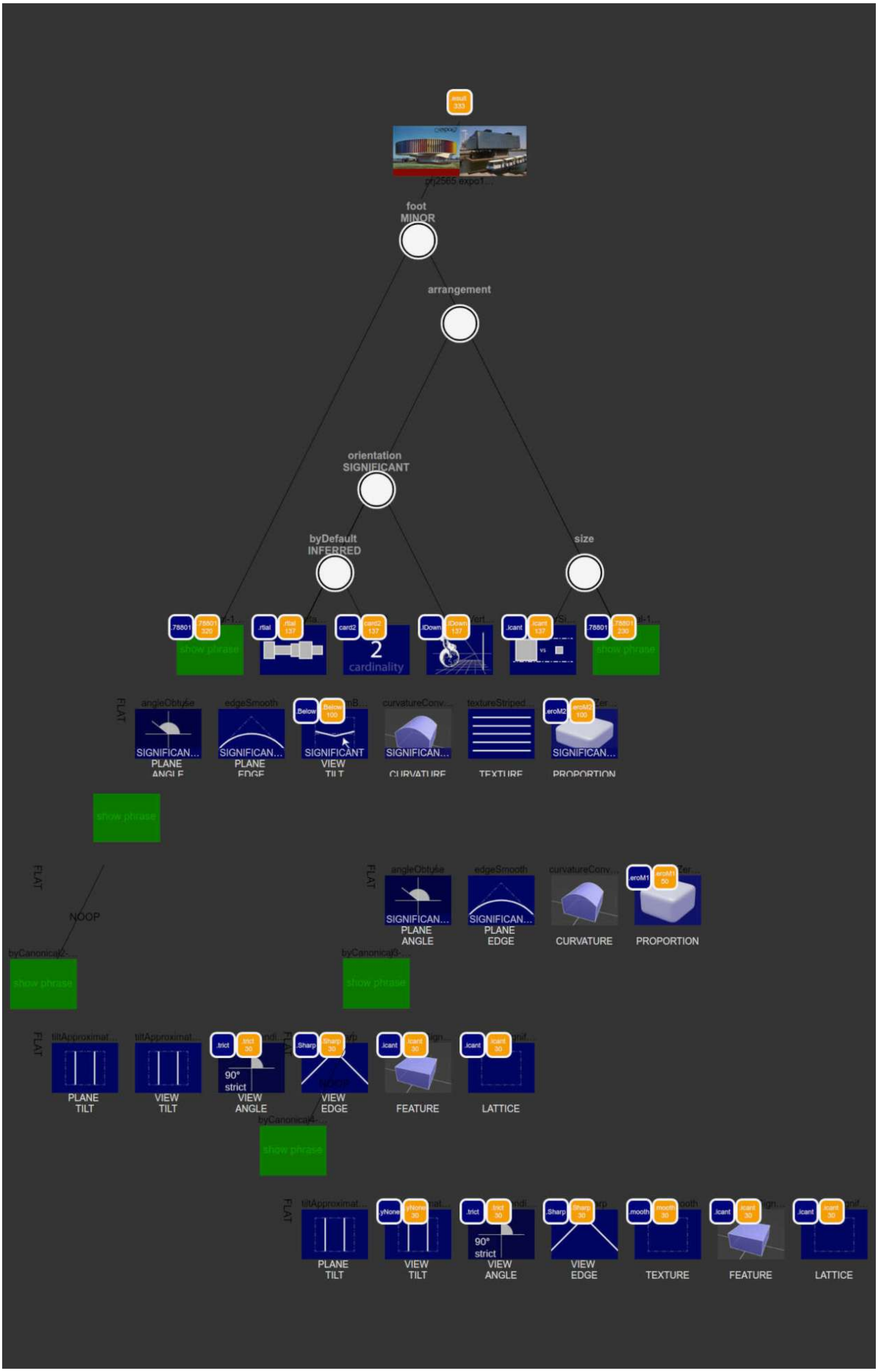


Figure 2: Interactive overlay of the comparison pair: E3 Kaleidoscope and E6 Quebec Pavilion. The application allows to follow the calculated values through the branches. It is possible to see the impact of each rule at each node (not visualised here). This is the exploratory bases for the visualisations in chapter 10.

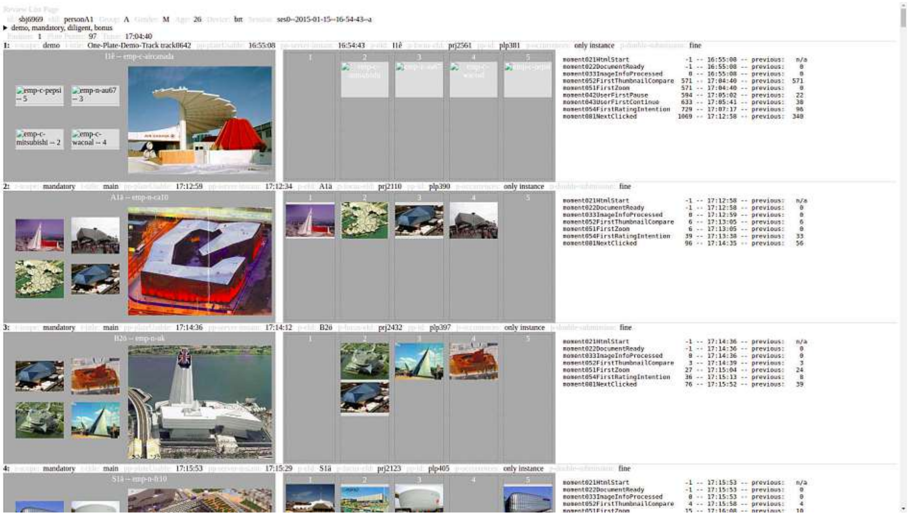


Figure 3: The quality assurance tool for the gathered empirical data allows to inspect each users "journey" through the rating screens. The left hand side column shows a bigger photograph of the focus pavilion, The middle column depicts the final rating.

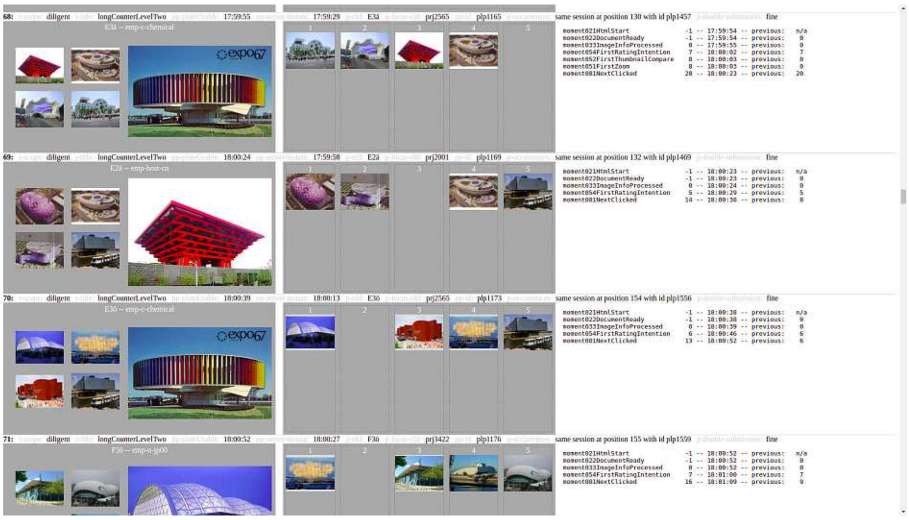


Figure 4: On this and the next Figure we can inspect how different users rated the E3 Kaleidoscope. The right hand side column show interaction data like the time spend by the user to complete the rating. For instance 28 seconds have been spend in the top row.

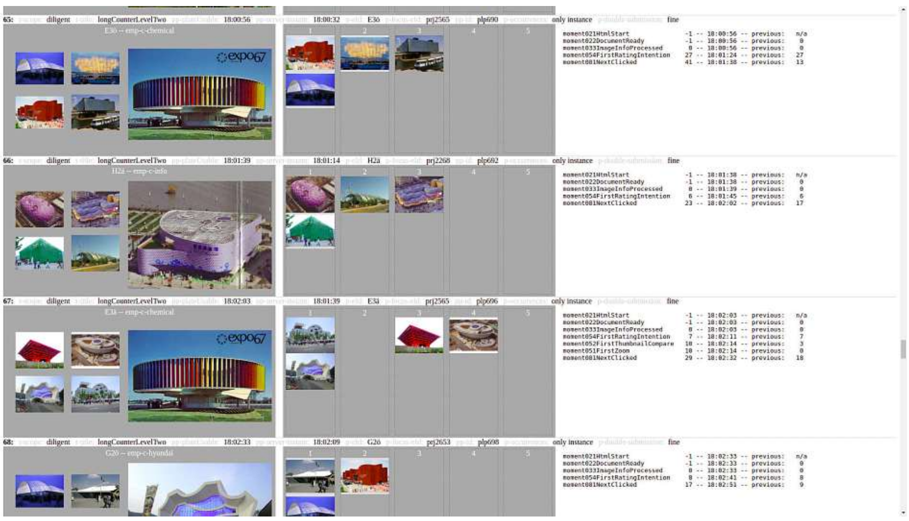


Figure 5: Again the E3 Kaleidoscope appears twice. We can see how this user is more cautious with rating in the "4" and "5" slots. The statistical average of 52 participant should level such difference is behaviour.

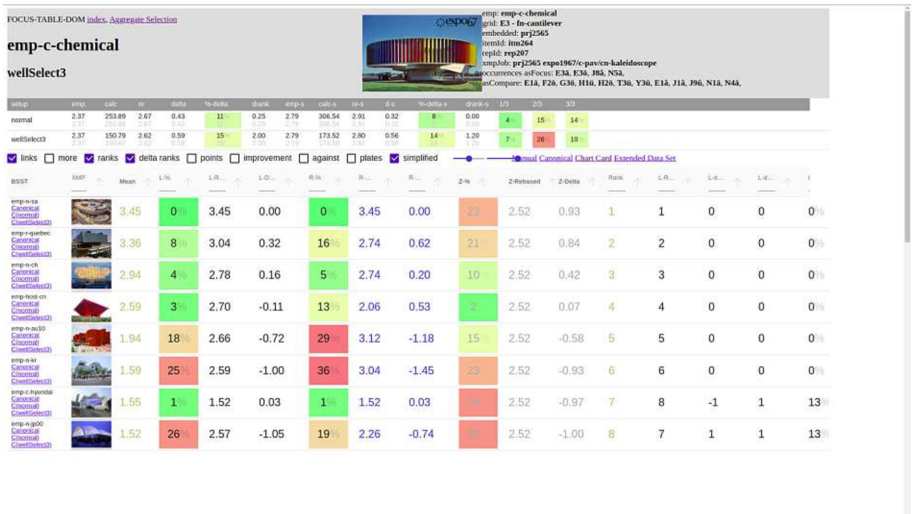


Figure 6: An interactive application to see calculated and empirical data side by side. Obviously an expert tool written by the author for the author. The "Mean" column shows *empirical* data (E.g. 3.45). All columns right of it show *calculated* data. Each green to red gradient and the next two columns form a group. The first group is the final "full system", the second group is the "six best performing", the last group is the reference "zero".

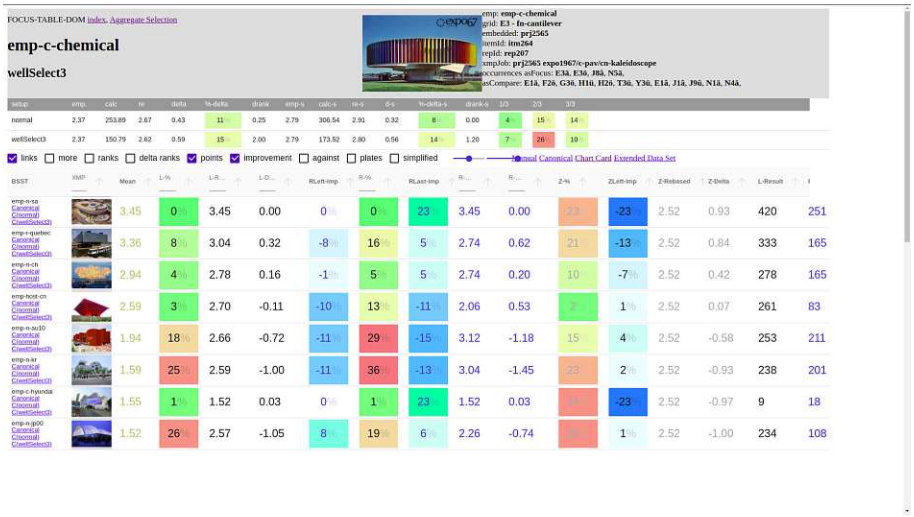


Figure 7: Additional columns can be toggled into view and expose further information. F.i. the blue to green gradients show show improvements of one group against an other. The depicted group "wellSelect3" is discussed in chapter 12.4.1 and Figure 340

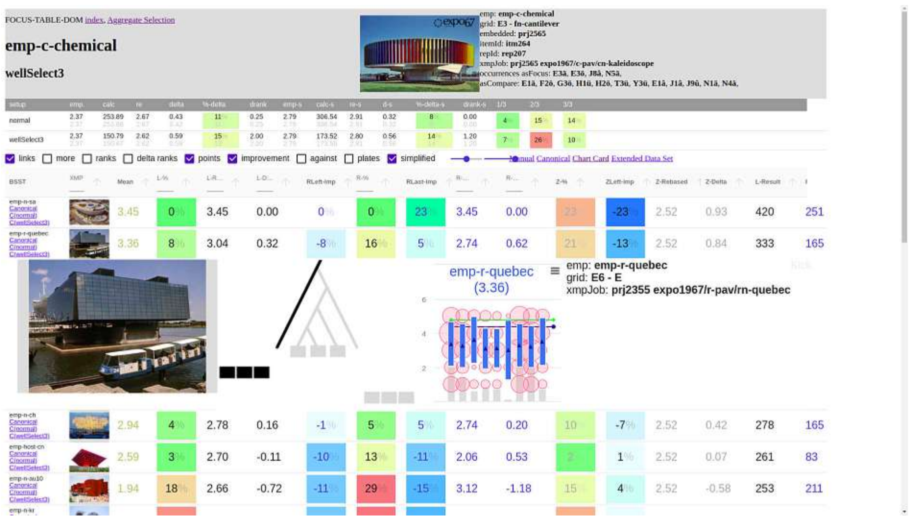
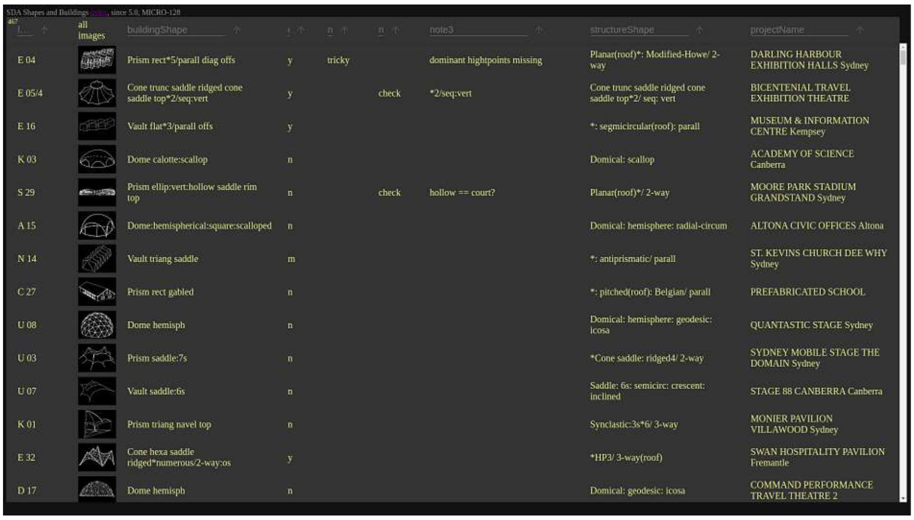


Figure 8: Additional contextual information, photos and deep links to other tools.

Figure 9: A web based filterable and sortable pivot table to explore the own data set. No traditional relational database technology was used. Therefore pivot tables like this allow to gain overview, focus on special properties, makes notes and apply tagging.



	all images	buildingShape				note3	structureShape	projectName
E 04		Prism rect*5/parall diag offs	y	tricky		dominant hightpoints missing	Planar(roof)*: Modified-Howe/ 2-way	DARLING HARBOUR EXHIBITION HALLS Sydney
E 05/4		Cone trunc saddle ridged cone saddle top*2/seq:vert	y		check	*2/seq:vert	Cone trunc saddle ridged cone saddle top*2/ seq: vert	BICENTENIAL TRAVEL EXHIBITION THEATRE
E 16		Vault flat*3/parall offs	y				*: segmicircular(roof): parall	MUSEUM & INFORMATION CENTRE Kempsey
K 03		Dome calotte:scallop	n				Domical: scallop	ACADEMY OF SCIENCE Canberra
S 29		Prism ellip:vert:hollow saddle rim top	n		check	hollow == court?	Planar(roof)*/ 2-way	MOORE PARK STADIUM GRANDSTAND Sydney
A 15		Dome:hemispherical:square:scalloped	n				Domical: hemisphere: radial-circum	ALTONA CIVIC OFFICES Altona
N 14		Vault triang saddle	m				*: antiprismatic/ parall	ST. KEVINS CHURCH DEE WHY Sydney
C 27		Prism rect gabled	n				*: pitched(roof): Belgian/ parall	PREFABRICATED SCHOOL
U 08		Dome hemisph	n				Domical: hemisphere: geodesic: icosa	QUANTASTIC STAGE Sydney
U 03		Prism saddle:7s	n				*Cone saddle: ridged4/ 2-way	SYDNEY MOBILE STAGE THE DOMAIN Sydney
U 07		Vault saddle:6s	n				Saddle: 6s: semicirc: crescent: inclined	STAGE 88 CANBERRA Canberra
K 01		Prism triang navel top	n				Synclastic:3s*6/ 3-way	MONIER PAVILION VILLAWOOD Sydney
E 32		Cone hexa saddle ridged*numerous/2-way:os	y				*HP3/ 3-way(roof)	SWAN HOSPITALITY PAVILION Fremantle
D 17		Dome hemisph	n				Domical: geodesic: icosa	COMMAND PERFORMANCE TRAVEL THEATRE 2

Figure 10: A web based filterable and sortable pivot table to explore the Structural Design Aid (SDA) data. Similar to the previous Figure, we can see tagging and notes in the middle. The second to the right column is the SDA own *Mnemonic Code*. It is a kind of short notation which is still human readable but tries to capture all the attributes in a text fragment. The SDA is discussed in chapter 5.4.3

2.5. Thank to open source

This software has not been possible without the use of Open Source Software (OSS). The author likes to thank all people and organisations that makes this possible. For the final software development task hardly any commercial product was used. It starts from the the operation system Ubuntu and further spans to:

At the backend:

- Eclipse Integrated Development Environment (IDE)
- Open source Java and Groovy programming languages.
- Gradle build tool
- Spring Boot stack with the Spring Framework at the core.
- Apache Jena semantic web framework, with its OWL capabilities.
- Joox library for XML processing.
- Webjars library to simplify the use of frontend libraries in a backend.
- Junit library as a foundation for unit tests.
- Supporting unit test libraries like: AssertJ, JsonPath, Mockito, XmlUnit
- Numerous further third party open source libraries that the Spring Boot stack builds upon, or the author was freely able to chose from. Some valuable Java libraries in use are: Jackson, Jool, Apache Commons-Math3, Apache PdfBox, Drewnoakes Metdata-extractor, se.fishtank Css-Selectors.

At the frontend:

- Visual Studio Code source code editor
- Atom source code editor
- Web browsers Chromium and Firefox
- JavaScript language embedded in the Chromium and Firefox web browsers.
- Polymer Web Component project with the associated Polymer Elements
- Plotly JavaScript chart library
- Numerous further third party open source libraries that the author was freely able to chose from. Some important JavaScript libraries in use are: cheonhyangzhang-paper-tags-input, vaadin-combo-box

The obvious exceptions of commercial software was the partial use of the Windows Operating System and the Google Chrome web browser. Though the technical core of Google Chrome is also based on the open source Chromium project. During one phase the Vaadin company generously granted a free academic license for their commercial *charting* Web Components to the author. The final version of the software does not require these any more.

Not directly related to the software, but as a prerequisite; the software Adobe Lightroom have been used to collect, sort and export thousands of photographs of World Exposition pavilions. Not related to the software but rather to visualisations in the main document the graphics software from the companies Adobe and Serif have been valuable. The author like to the the Adobe for the affordable academic licensing of the Adobe CS suite.

The hundred of pages of the main document have been written in LibreOffice Writer.

3. Example XML

This section will show the full XML data of two of the 80 World Exposition pavilions:

- E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)
  This pavilion is our most discussed “Canonical Example” in the main document. For instance in chapters 6.5.4, 6.6.5, 10.1, 10.2, 10.3, 10.4, 11.3, 12.1.5, 12.2.2
  The data structure is quite simple.
  A visualisation of the XML as a two dimensional tree can be found in Figure 11.
  A full visualisation including the Periphrase items can be found in Appendix A.

- A4 - Expo 2010 Russia Pavilion (Shanghai)
  This pavilion is discussed as a more challenging example in chapter 8.3.
  The data structure is a bit more involved.
  A visualisation of the XML as a two dimensional tree can be found in Figure 15.
  A full visualisation including the Periphrase items can be found in Appendix A.

XML Semantics Disclaimer

When we peek into the XML we can see that the data contain elements like: <syntax-sentence>, <syntax-phrase>, <syntax-noun>, <syntax-verb>, and <syntax-adj>. These terms stem from the early stage of the research, before the conceptual shift took place, as described in chapter 4.2.. The idea to be very close to Generative Linguistics was dropped at that point. Still the terms have not been changed. The terms still work for structuring the XML document. But there is no strong connection to Generative Linguistics anticipated. The names could very well also be just <syntax-x>, <syntax-y>, <syntax-z>.

We will first show the complete XML of the E3 Kaleidoscope on a single print page and then explain the upcoming structure of the more involved A4 Russia Pavilion.

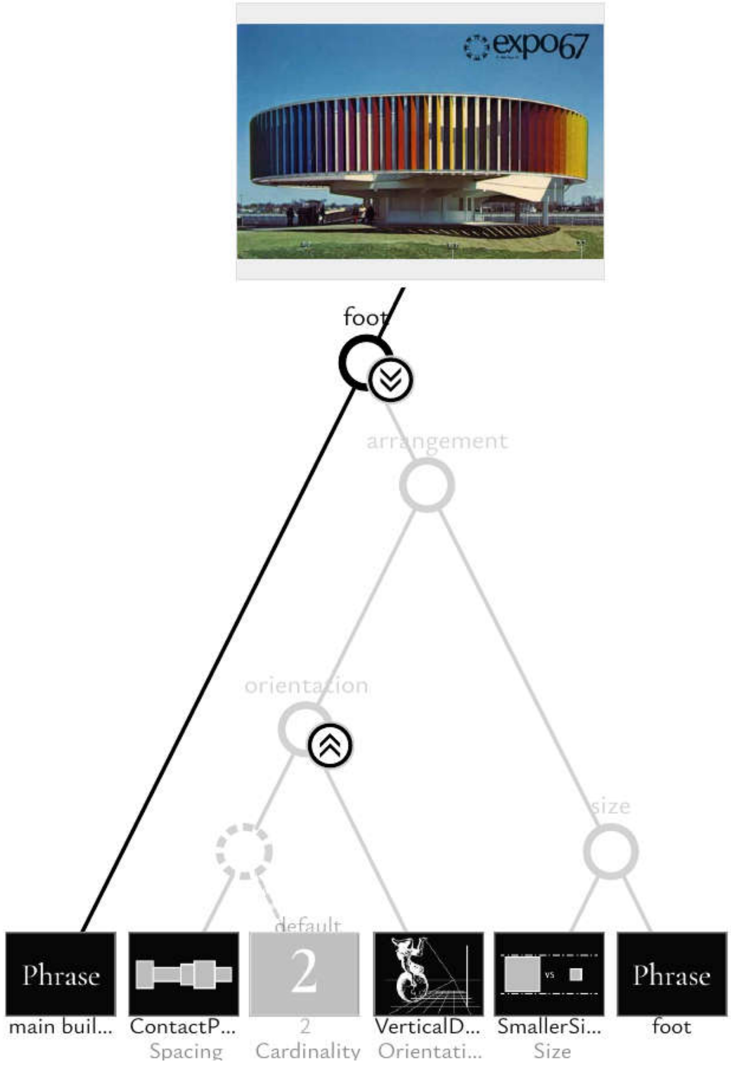


Figure 11: E3 - Expo 1967 Kaleidoscope Pavilion (Montreal) as it appears in Appendix A (with bigger photo). The default item of cardinality2 is rendered in a light grey and with dashed lines. The circle with the two upwards arrows indicate the significant orientation. The two downwards arrows indicate that the whole second Periphrase of the base is consider of minor significance once it is dominated by the main distinct building part: the cylinder. The minor significance of the whole branch is also rendered as grey lines of the tree diagram itself.

Figure 12: E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)

Figure 13: E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)

Figure 14: E3 - Expo 1967 Kaleidoscope Pavilion (Montreal)

images-linked-appendix-e/ca_montreal__c-pav_cn-kaleidoscope_(474)__viaFlickr_userThePieShopsCollection__7766428922_144da4f956_b.jpg
images-linked-appendix-e/ca_montreal__c-pav_cn-kaleidoscope_(474)__viaExpo67NefCa__kaliedscope2_expo67.jpg
images-linked-appendix-e/ca_montreal__c-pav_cn-kaleidoscope_(474)__viaArchivesdemontrealIcaAtomOrg__VM94-EX136-235.jpg

```
<syntax-sentence
   t="prj2565 expo1967/c-pav/cn-kaleidoscope E3 fn-cantilever"
   uid="emp-c-chemical"
   layer="COMPOSITION" xmlns="http://www.jurewicz.info/bsst"
   xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
   xsi:schemaLocation="http://www.jurewicz.info/bsst bsst.xsd">
  <domain-building uid="emp-c-chemical"></domain-building>
  <syntax-join t="foot" sig="MINOR">
    <syntax-phrase layer="IDENTITY">
      <flat-list>
        <flat-item slot="ANGLE_PLANE" sig="SIGNIFICANT">
          <syntax-noun uid="angleObtuse" pov="PLANE"></syntax-noun>
        </flat-item>
        <flat-item slot="EDGE_PLANE" sig="SIGNIFICANT">
          <syntax-noun uid="edgeSmooth" pov="PLANE"></syntax-noun>
        </flat-item>
        <flat-item slot="TILT_VIEW" sig="SIGNIFICANT" behave="ADD">
          <syntax-noun uid="tiltViewFromBelow" pov="VIEW"></syntax-noun>
        </flat-item>
        <flat-item slot="CURVATURE_ANY" sig="SIGNIFICANT">
          <syntax-noun uid="curvatureConvexStraight"></syntax-noun>
        </flat-item>
        <flat-item slot="TEXTURE_ANY">
          <syntax-noun uid="textureStripedRegular"></syntax-noun>
        </flat-item>
        <flat-item slot="PROPORTION_ANY" sig="SIGNIFICANT">
          <syntax-noun uid="proportionZeroZeroM2"></syntax-noun>
        </flat-item>
      </flat-list>
    </syntax-phrase>
    <syntax-join t="arrangement">
      <syntax-join t="size">
        <syntax-phrase layer="IDENTITY">
          <flat-list>
            <flat-item slot="ANGLE_PLANE" sig="SIGNIFICANT">
              <syntax-noun uid="angleObtuse" pov="PLANE"></syntax-noun>
            </flat-item>
            <flat-item slot="EDGE_PLANE" sig="SIGNIFICANT">
              <syntax-noun uid="edgeSmooth" pov="PLANE"></syntax-noun>
            </flat-item>
            <flat-item slot="CURVATURE_ANY">
              <syntax-noun uid="curvatureConvexStraight"></syntax-noun>
            </flat-item>
            <flat-item slot="PROPORTION_ANY">
              <syntax-noun uid="proportionZeroZeroM1"></syntax-noun>
            </flat-item>
          </flat-list>
        </syntax-phrase>
      <syntax-verb uid="sizeSmallerSignificant"></syntax-verb>
      </syntax-join>
      <syntax-join t="orientation" sig="SIGNIFICANT">
        <syntax-verb uid="spacingContactPartial"></syntax-verb>
        <syntax-adj uid="orientationVerticalDown"></syntax-adj>
      </syntax-join>
    </syntax-join>
  </syntax-join>
</syntax-sentence>
```

The following is a simplified colour coded depiction of A4 - Expo 2010 Russia Pavilion to highlight different parts in the tree hierarchy:

```
<syntax-sentence>
  <syntax-join>
    <syntax-join>
      <syntax-phrase>
        <flat-list><flat-item><syntax-noun /></flat-item></flat-list> (A)
      </syntax-phrase>
      <syntax-join>
        <syntax-join>
          <syntax-phrase>
            <flat-list><flat-item><syntax-noun /></flat-item></flat-list> (B)
          </syntax-phrase>
          <syntax-verb /> (2)
        </syntax-join>
        <syntax-verb /> (1)
      </syntax-join>
    </syntax-join>
    <syntax-join>
      <syntax-join>
        <syntax-join>
          <syntax-phrase>
            <flat-list><flat-item><syntax-noun /></flat-item></flat-list> (C)
          </syntax-phrase>
          <syntax-join>
            <syntax-verb /> (6)
            <syntax-adj /> (7)
          </syntax-join>
        </syntax-join>
        <syntax-verb /> (5)
      </syntax-join>
      <syntax-join>
        <syntax-verb /> (3)
        <syntax-adj /> (4)
      </syntax-join>
    </syntax-join>
  </syntax-join>
</syntax-sentence>
```

- The black coloured font represent the tree structure of the Building Shape Syntax Tree.
- The red coloured font represent Syntax Tree Classification items, at the bottom row of the two dimensional tree. The numbers correspond to the red circles in Figure 15.
- The orange coloured font are the Syntax Tree *containers* for the three Periphrases. They are also at the bottom of the two dimensional tree.
- The cyan colour are the three Periphrases. The letters A,B,C correspond to the cyan circles in Figure 15.

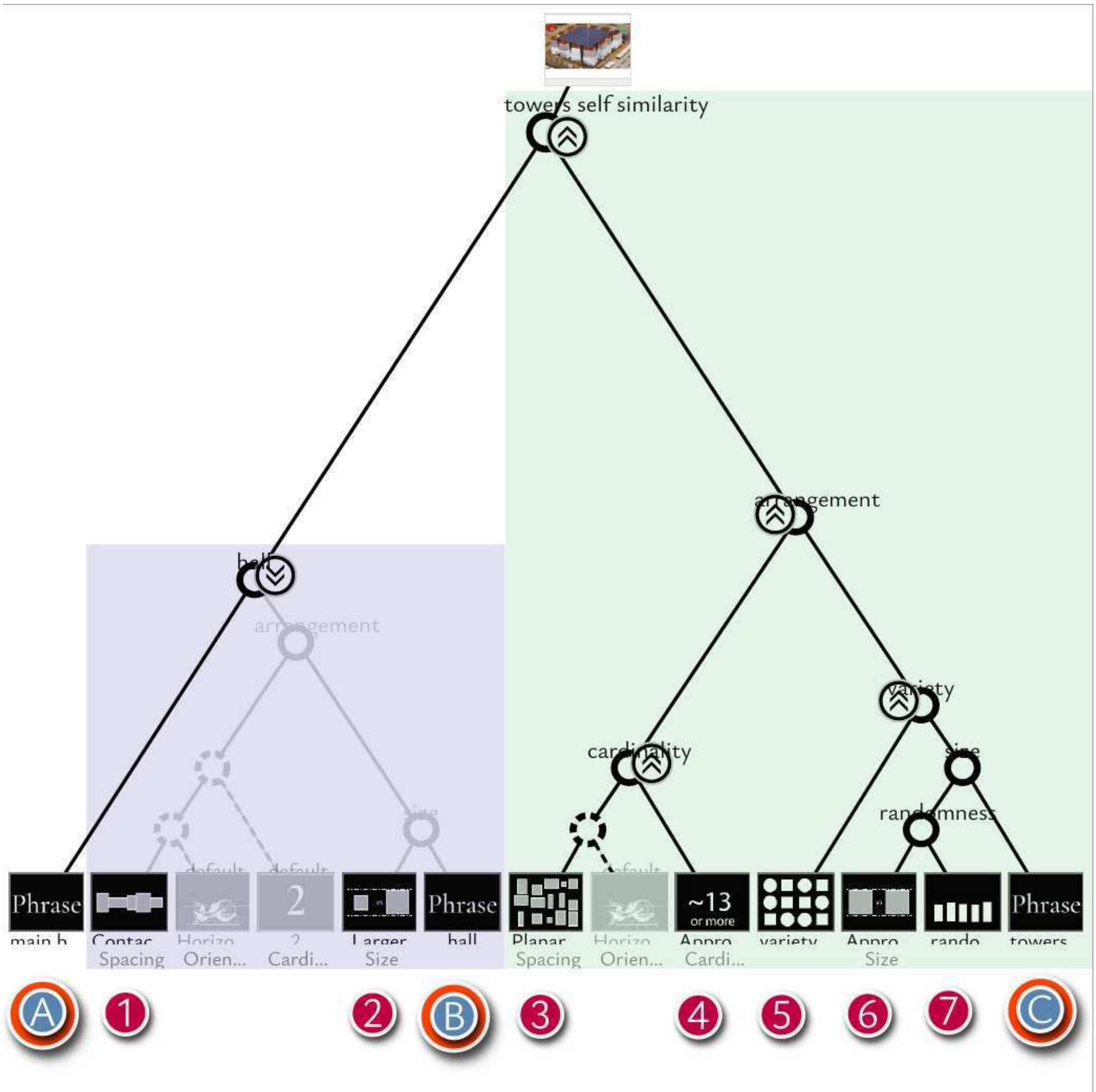


Figure 15: A4 - Expo 2010 Russia Pavilion (Shanghai), annotated Syntax Tree

Figure 16: A4 - Expo 2010 Russia Pavilion (Shanghai)
Aerial View

Figure 17: A4 - Expo 2010 Russia Pavilion (Shanghai)
Pedestrian View

Figure 18: A4 - Expo 2010 Russia Pavilion (Shanghai)
Details View

The following is the full XML of the A4 Russia Pavilion including all three Periphrases. The Periphrases appear as <flat-list> including multiple <flat-item>:


```
<syntax-sentence t="prj2163 expo2010/n-pav-ru/nn-russia A4 fn-faceted"
    uid="emp-n-ru" layer="COMPOSITION" xmlns="http://www.jurewicz.info/bsst"
    xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
    xsi:schemaLocation="http://www.jurewicz.info/bsst bsst.xsd">
  <domain-building uid="emp-n-ru"></domain-building>
  <syntax-join t="towers self similarity" sig="SIGNIFICANT">
    <syntax-join t="hall" sig="MINOR">
      <syntax-phrase layer="IDENTITY">
        <flat-list>
          <flat-item slot="ANGLE_PLANE">
            <syntax-noun uid="anglePerpendicularOff" pov="PLANE"></syntax-noun>
          </flat-item>
          <flat-item slot="ANGLE_VIEW">
            <syntax-noun uid="anglePerpendicularOffMinor" pov="VIEW"></syntax-noun>
          </flat-item>
          <flat-item slot="ANGLE_VIEW">
            <syntax-noun uid="angleObtuse" pov="VIEW"></syntax-noun>
          </flat-item>
          <flat-item slot="TILT_VIEW" sig="MINOR" behave="ADD">
            <syntax-noun uid="tiltWidenMinor" pov="VIEW"></syntax-noun>
          </flat-item>
          <flat-item slot="TILT_VIEW" sig="SIGNIFICANT">
            <syntax-noun uid="tiltTaperMinor" pov="VIEW"></syntax-noun>
          </flat-item>
          <flat-item slot="TEXTURE_ANY">
            <syntax-noun uid="textureFacetedIrregular"></syntax-noun>
          </flat-item>
          <flat-item slot="LATTICE_ANY">
            <syntax-noun uid="latticeNoise"></syntax-noun>
          </flat-item>
          <flat-item slot="LATTICE_ANY" sig="MINOR" behave="ADD">
            <syntax-noun uid="latticeStrechUnproportional"></syntax-noun>
          </flat-item>
          <flat-item slot="LATTICE_ANY" sig="MINOR" behave="ADD">
            <syntax-noun uid="latticeShear"></syntax-noun>
          </flat-item>
            <flat-item slot="PROPORTION_ANY" sig="SIGNIFICANT">
            <syntax-noun uid="proportionZeroZeroP1"></syntax-noun>
          </flat-item>
        </flat-list>
      </syntax-phrase>
      <syntax-join t="arrangement">
        <syntax-join t="size">
          <syntax-phrase layer="IDENTITY">
            <flat-list>
              <!-- this is no error that this is so empty, -->
              <!-- because the box in the middle is just a box -->
              <flat-item slot="PROPORTION_ANY">
                <syntax-noun uid="proportionZeroZeroM2"></syntax-noun>
              </flat-item>
            </flat-list>
          </syntax-phrase>
          <syntax-verb uid="sizeLarger"></syntax-verb>
        </syntax-join>
        <syntax-verb uid="spacingContactPartial"></syntax-verb>
      </syntax-join>
    </syntax-join>
    <syntax-join t="arrangement" sig="SIGNIFICANT">
      <syntax-join t="variety" sig="SIGNIFICANT">
        <syntax-join t="size">
          <syntax-phrase layer="IDENTITY">
            <flat-list>
              <!-- copy and paste from main one -->
              <flat-item slot="ANGLE_PLANE">
                <syntax-noun uid="anglePerpendicularOff" pov="PLANE"></syntax-noun>
              </flat-item>
              <flat-item slot="ANGLE_VIEW">
```

```
        <syntax-noun uid="anglePerpendicularOffMinor" pov="VIEW"></syntax-noun>
      </flat-item>
      <flat-item slot="ANGLE_VIEW">
        <syntax-noun uid="angleObtuse" pov="VIEW"></syntax-noun>
      </flat-item>
      <flat-item slot="TILT_VIEW" sig="MINOR" behave="ADD"><!-- sig="SIGNIFICANT" -->
        <syntax-noun uid="tiltWidenMinor" pov="VIEW"></syntax-noun>
      </flat-item>
      <flat-item slot="TILT_VIEW" sig="SIGNIFICANT">
        <syntax-noun uid="tiltTaperMinor" pov="VIEW"></syntax-noun>
      </flat-item>
      <flat-item slot="TEXTURE_ANY">
        <syntax-noun uid="textureFacetedIrregular"></syntax-noun>
      </flat-item>
      <flat-item slot="LATTICE_ANY">
        <syntax-noun uid="latticeNoise"></syntax-noun>
      </flat-item>
      <flat-item slot="LATTICE_ANY" sig="MINOR" behave="ADD">
        <syntax-noun uid="latticeStrechUnproportional"></syntax-noun>
      </flat-item>
      <flat-item slot="LATTICE_ANY" sig="MINOR" behave="ADD">
        <syntax-noun uid="latticeShear"></syntax-noun>
      </flat-item>
      <flat-item slot="PROPORTION_ANY" sig="SIGNIFICANT">
        <syntax-noun uid="proportionZeroZeroP1"></syntax-noun>
      </flat-item>
    </flat-list>
  </syntax-phrase>
  <syntax-join t="randomness">
    <syntax-verb uid="sizeApproximatelySame"></syntax-verb>
    <syntax-adj uid="randomMinor"></syntax-adj>
  </syntax-join>
</syntax-join>
<syntax-verb uid="varietySome"></syntax-verb>
</syntax-join>
<syntax-join t="cardinality" sig="SIGNIFICANT">
  <syntax-verb uid="spacingPlanarGapPartial"></syntax-verb>
  <syntax-adj uid="cardApproximatly13OrMore"></syntax-adj>
</syntax-join>
</syntax-join>
</syntax-join>
</syntax-sentence>
```