TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

DIPLOMARBEIT

ARCOUSTICON

interactive, space-creating, digital MIDI instrument (synthesizer)

ausgeführt zum Zwecke der Erlangung
des akademischen Grades
eines Diplom-Ingenieurs/
Diplom-Ingenieurin

unter der Leitung
Ass. Prof. Dipl.-Ing. Dr.techn. Peter G. Auer

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ABSTRACT

The ***CONNECTION BETWEEN ARCHITECTURE AND MUSIC*** as abstract forms of art has been rising human interest since at least the sixth century BC. Based on harmony, rhythm, and proportion, both share a deep cultural lineage. Ideas generated by cultural needs and moods in society, technical capabilities, as well as the depth of knowledge of physical parameters, go through a filter of individual interpretation and emotional reflection of the author every time he creates.

Today, in the ***ERA OF INFORMATION OVERLOAD***, the most challenging thing for designers and architects is to find their ***OWN STARTING POINT*** among numerous practices, design methods, and ideas in their field.

In this paper, I explore the symbiosis of music and architecture as a connection between their constituent components.

This approach allows me to identify possible relations not only between music and architecture, but also between the components in these disciplines which are on the outline or in the overlapping area with others, such as art or biology, psychology or digital design. That gives the author an opportunity to ***LOOK*** at the problem ***FROM DIFFERENT ANGLE*** and choose the best tools to reveal his or her fundamental idea and help to realize it.

The design process itself is the primary purpose of the project. It is based on the interconnection between four related areas:

ARCHITECTURE:
MOVEMENT + SPACE
MUSIC:
SOUND + RULES

"Architecture is frozen music",
Johann Wolfgang von Goethe, 1829.
The question is what happens if we try to "unfreeze" music, and let architecture move?

My research in this field leads to the discussion of themes such as: literally and metaphorically (re)presented movement in architecture; analysis of different approaches to the representation of musical flow in the shape and form of the architectonic structure. The following areas are also discussed: the active bending method as a form-finding approach, kinetic tools capable of generating the form in real time, and the possibilities of analog and digital sound generation.

The combination of these parameters into one interactive system (that follows different rules) determines the design of interactive musical pavilion ***"ARCOUSTICON"***, as a real-time digital synthesizer and visualizer.

The design process in this work is an experimental process, an attempt to find out relevant interconnections between sound and form, without a clearly defined design brief. In order to find potential development vectors for the music pavilion design, I am using my own emotional filters and ***EMPIRICAL RESEARCH METHODS.***

The ***STARTING POINT*** of the design process is the idea of presenting ***SOUND*** with tangible materials ***AS TIME CHANGEABLE FLOW IN ARCHITECTURE***.

In other words, this is an attempt to move away from the virtual dimension of sound visualization (already numerously represented by virtual audio-visualizers), to the physical dimension of real space, with the opportunity for ***TACTILE AND ACOUSTIC INTERACTION***. The pavilion shape is an optical, time changeable, moving “picture” of sound and music visualized in the physical world.

THIS DYNAMIC SOUND SCULPTURE INTERACTS WITH ANY OBSERVER, AND IN RESPONSE TO THE TOUCH GENERATES NEW FORMS. The interconnection between eye and mind happens not only intellectually but also emotionally, sensorially and spiritually.

(ABSTRACT)

Die ***VERBINDUNG VON ARCHITEKTUR UND MUSIK*** als abstrakte Formen der Kunst hat seit mindestens dem sechsten Jahrhundert v. Chr. ein zunehmendes menschliches Interesse geweckt. Basierend auf Harmonie, Rhythmus und Proportion, teilen beide eine tiefe kulturelle Linie. Ideen, die durch kulturelle Bedürfnisse und Stimmungen in der Gesellschaft, technische Fähigkeiten sowie die Tiefe des Wissens über physische Parameter erzeugt werden, durchlaufen jedes Mal einen Filter der individuellen Interpretation und emotionalen Reflektionen des Autors.

Heute, in der ***ZEIT DER INFORMATIONSÜBERFLUTUNG***, die größte Herausforderung für Designer und Architekten besteht darin, unter zahlreichen Praktiken, Designmethoden und Ideen auf ihrem Gebiet einen ***EIGENEN AUSGANGSPUNKT*** zu finden.

In diese Arbeit erkunde ich die Symbiose von Musik und Architektur als Verbindung zwischen ihren Bestandteilen. Dieser Ansatz ermöglicht es mir, mögliche Beziehungen nicht nur zwischen Musik und Architektur zu identifizieren, sondern auch zwischen den Komponenten in diesen Disziplinen, die auf dem Umriss oder im Überschneidungsbereich mit anderen, wie Kunst oder Biologie, Psychologie oder digitales Design sich befinden. Das gibt dem Autor die Möglichkeit, das Problem ***AUS EINEM ANDEREN BLICKWINKEL ZU BETRACHTEN*** und die besten Werkzeuge zu wählen, um seine Grundidee zu enthüllen und zu helfen, sie zu realisieren.

Der Entwurfsprozess selbst ist der Hauptzweck des Projekts. Es basiert auf der Verbindung zwischen vier verwandten Bereichen:

ARCHITEKTUR:
BEWEGUNG + RAUM
MUSIK:
KLANG + REGELN

"Architektur ist gefrorene Musik", Johann Wolfgang von Goethe, 1829. Die Frage ist, was passiert, wenn wir versuchen, die Musik "aufzutauen" und Architektur bewegen zu lassen?

Meine Forschung auf diesem Gebiet führt zur Diskussion von Themen wie: buchstäblich und metaphorisch (re)präsentierte Bewegung in der Architektur; Analyse verschiedener Ansätze zur Darstellung des fließendes Musik in Form der architektonischen Struktur. Die folgenden Bereiche werden ebenfalls diskutiert: die aktive Biegemethode als Formfindungmethode, kinetische tools, die Form in Echtzeit erzeugen, und die Möglichkeiten der analogen und digitalen Klanggenerierung.

Die Kombination dieser Parameter zu einem interaktiven System (das unterschiedlichen Regeln folgt) bestimmt das Design des interaktiven Musikpavillons ***"ARCOUSTICON"***, als digitalen Echtzeit-Synthesizer und Visualizer.

Der Entwurfsprozess in dieser Arbeit ist ein experimenteller Prozess, ein Versuch, relevante Verbindungen zwischen Klang und Form zu finden, ohne eine klar umrissene Designvorgabe. Um mögliche Entwicklungsvektoren für das Musikpavilliondesign zu finden, verwende ich meine eigenen Emotionsfilter und ***EMPIRISCHEN FORSCHUNGSMETHODEN.***

Der ***AUSGANGSPUNKT*** des Designprozesses ist die Idee, ***KLANG*** mit greifbaren Materialien ***ALS ZEITVERÄNDERLICHEN FLUSS IN DER ARCHITEKTUR*** zu präsentieren.

Mit anderen Worten ist dies ein Versuch, sich von der virtuellen Dimension der Klangvisualisierung (die bereits zahlreich durch virtuelle Audio-Visualisierer repräsentiert wird) in die physische Dimension des realen Raums mit der Möglichkeit ***TAKTILER UND AKUSTISCHER INTERAKTION*** zu bringen. Die Pavillonform ist ein optisches, zeitveränderliches, bewegendes "Bild" aus Klang und Musik, visualisiert in der physischen Welt.

DIESE DYNAMISCHE KLANGSKULPTUR INTERAGIERT MIT JEDEM BEOBACHTER UND ERZEUGT ALS REAKTION AUF DIE BERÜHRUNG NEUE FORMEN. Die Verbindung zwischen Auge und Geist geschieht nicht nur intellektuell, sondern auch emotional, sensorisch und spirituell.

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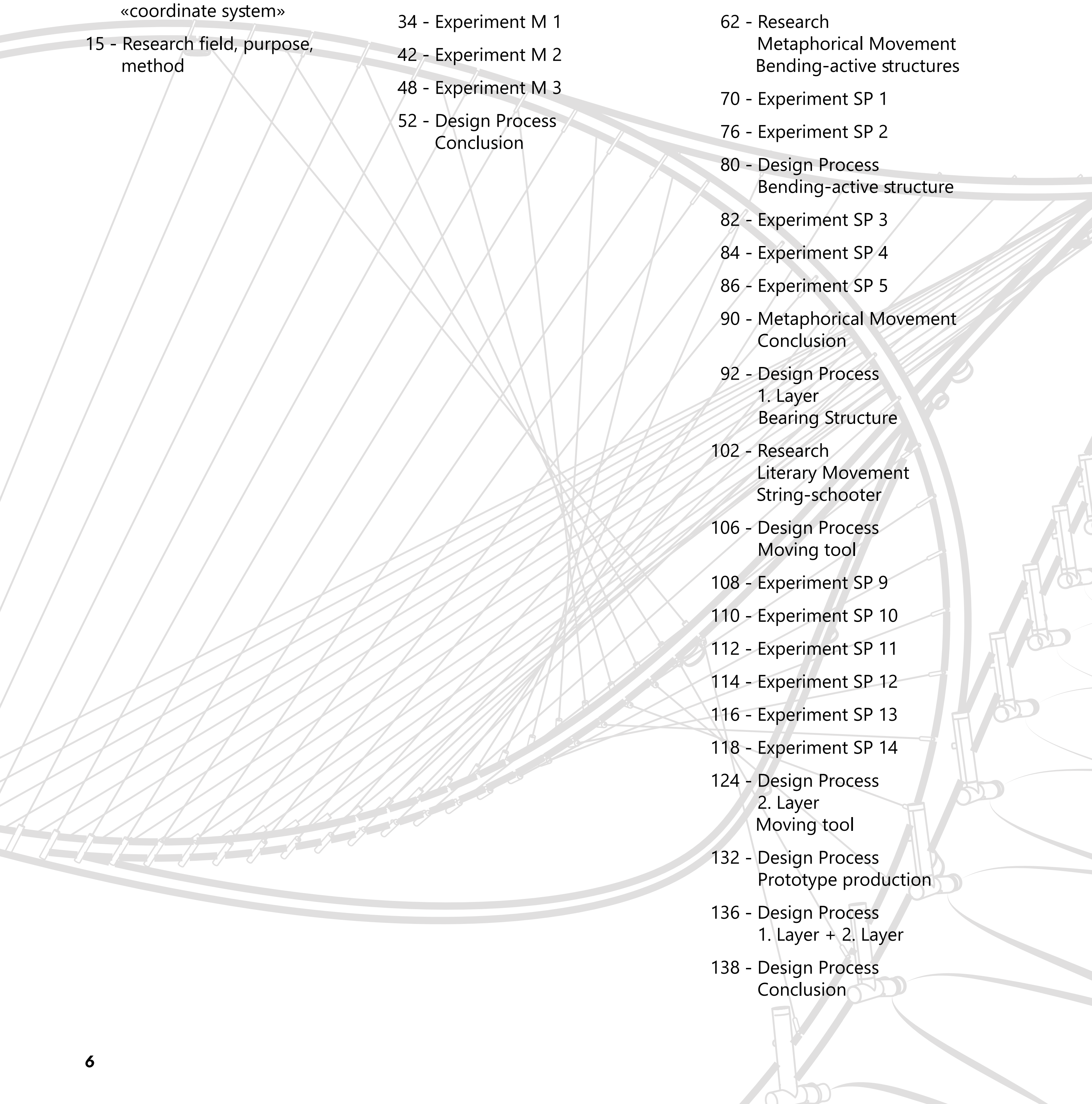

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ARCOUSTICON

INTRODUCTION

"When I see architecture that moves me, I hear music in my Inner ear."
Frank Lloyd Wright

Architecture has often referred to music in search of creative inspiration. Sound and music are integral parts of the arts and our lives, surrounding us everywhere and every time. That is why, due to the individual designer attitude, music will always leave a unique imprint on the project.

The world of sounds impresses and touches us consciously and unconsciously. Whether we like it or not, a sound will always influence us (good or bad), while music will always inspire us. Both affect our sensory system through which we can perceive, study and understand not only our surrounding environment but also our inner world.

Each artist, first and foremost, uses the filter of his own perception, musical experience, and personal associations. That is why, at the intersection of these two worlds - architecture and music - we find a whole range of approaches and concepts, that are determined not only by design problems, economic factors, technical achievements, and the cultural environment, but also by something more intimate, intuitive, subconscious and very personal.

There is no single correct approach or methodology. For each author, the answer to the question: What is the symbiosis of architecture and music? is very individual, and each has his own original position.

This position is a starting point in the "coordinate system" of the author. It determines his or her location in the space of ideologies, concepts, technologies, methods and cultural heritage of predecessors. From that point, the vector of creativity begins and gives the impulse for further development.

"Architecture is not just an intellectual or abstract exercise, it is an emotional experience just as music is. It is very precise, it cannot be off by one half of a vibration because everyone would know that it doesn't sound right. It has to communicate to the soul and everybody has to share it in a deep emotional way. It is always about a performance and what happens after the performance. When you leave a building, it is like leaving a piece of music. It is still in you and still with you.."

Daniel Libeskind 2014
interviewed in "The Talks"

STARTING POINT AND «COORDINATE SYSTEM» RESEARCH

The answer to the question: What is the symbiosis of sound and space, music and architecture? for each different project is always individual. However, a set of components (parameters, disciplines, and methods) in architecture and music will always remain the same for everyone. Considering these elements, not as a system of their certain combinations, but separately, as individual parameters, we can get an overview of their possible connections and developing vectors.

In this work, the representation of these connections by a diagram allows me to design my own system of their combinations. This approach makes possible the creation of a various unique system by implementing the same parameters. We can see a metaphorical parallel between this design process and creation of the musical instrument. The musical instrument obtains its unique sounding, due to the collection of its individual overtones.

Creating such a ***"coordinate system"*** like this allows the designer to work with different kinds of data, and makes it easier to decide, which one is important and exciting and which one is not. In our era of information overload, this approach of „explode" and „join" makes it easier to structure the work and always have an overlook of all kinds of opportunities.

The organizational chart on pages 12-13 represents that kind of "coordinate system" in this diploma and represents the main starting points, directions, and research fields. The construction uses the basic parameters of music and architecture in the context of their own interaction and their interaction with humans. This structure is a roadmap for the given project. First and foremost, it includes the specific elements that reveal the fundamental conceptual idea in the design process in the best possible way.

I consider the connection between architecture and music as a product of different relations between their following parts:
architecture=movement+space
music = sound + rules

By this approach, the data (parameters), that are "joined" (connected) in a new system, are formed after "exploding" architecture and music into its constituent parts. For the **ARCOUSTICON** pavilion project, as mentioned above, such constituent parts are movement and space as well as sound and rules. Moreover, these four parameters can also be "exploded" into their own ***constituent parts***.

For example movement in architecture can be seen as metaphorical representation *("frozen music")* or literally presentation *(kinetic architecture)*. Working with space, we can design in a physical world or an interactive virtual space *("virtual art")*.

Moreover, if we create architectonic space in a physical world, the building materials which we are choosing also make a difference. The approaches will be different by designing space with light *(A. McCall projects)* or sound *(B. Leitner projects)* and by designing using more ***"touchable,"*** tactile materials.

Music, as a combination of sounds and rules of their placing in time, produces many sources of data. Digital or analog sound systems could be a part of the design. Sometimes parts of the design are not only found in architecture but in other disciplines, like painting or biology.

Take, for example, the connection between music and painting as an instance of interaction. The work of the italian musician and computer technician Giovanni Pala, which is called *"Uncover the hidden music in Da Vinci`s "Last Supper",* 2003, perfectly expresses this combination. Within the painting, Giovanni Pala interpreted the pieces of bread and palms of Jesus and the Apostles as separate notes, which refers to the musical notation on a musical sheet.

Another example of such an interaction is music and biology, like in *"Play your DNA"* music box. In this case, the individual genotype is translated into the notes, therefore creating a melody.

The amount of usability of these kinds of connections in architecture depends on the specific idea for the project. However, it is helpful to be open-minded during the creative process, to have a wide perspective to be able to see the possibilities for design from different angles.

The proportion between architectural and musical parts in the projects also matters. If the primary focus falls on the musical part, then space is going to be a tool for musical needs.

So for example, in Bernhard Leitner's sound structure *"Serpentinate",* 2004, sound creates an "acoustic walls." In this particular case, sound serves as a building material, literally untouchable, but nevertheless able to provide for the room separation and identification.

If the primary focus falls on the architectural part, musical parameters are going to be a tool for architectural needs, as Coop Himmelb(l)au's *"Pavilion 21 MINI Opera Space",* 2008-2010. The design process of this pavilion is based on a parametric design approach, where musical parameters are the key incoming data for the shape generation. The segment of the song *"Purple Haze"* by Jimi Hendrix determines the extrusion of the volume(spikes). And the segment of *"Non-ho Timor: verrò!"* by Wolfgang Amadeus Mozart, in "Don Giovanni", Scene 15 was used as the database for determining the direction of the volume(spikes).

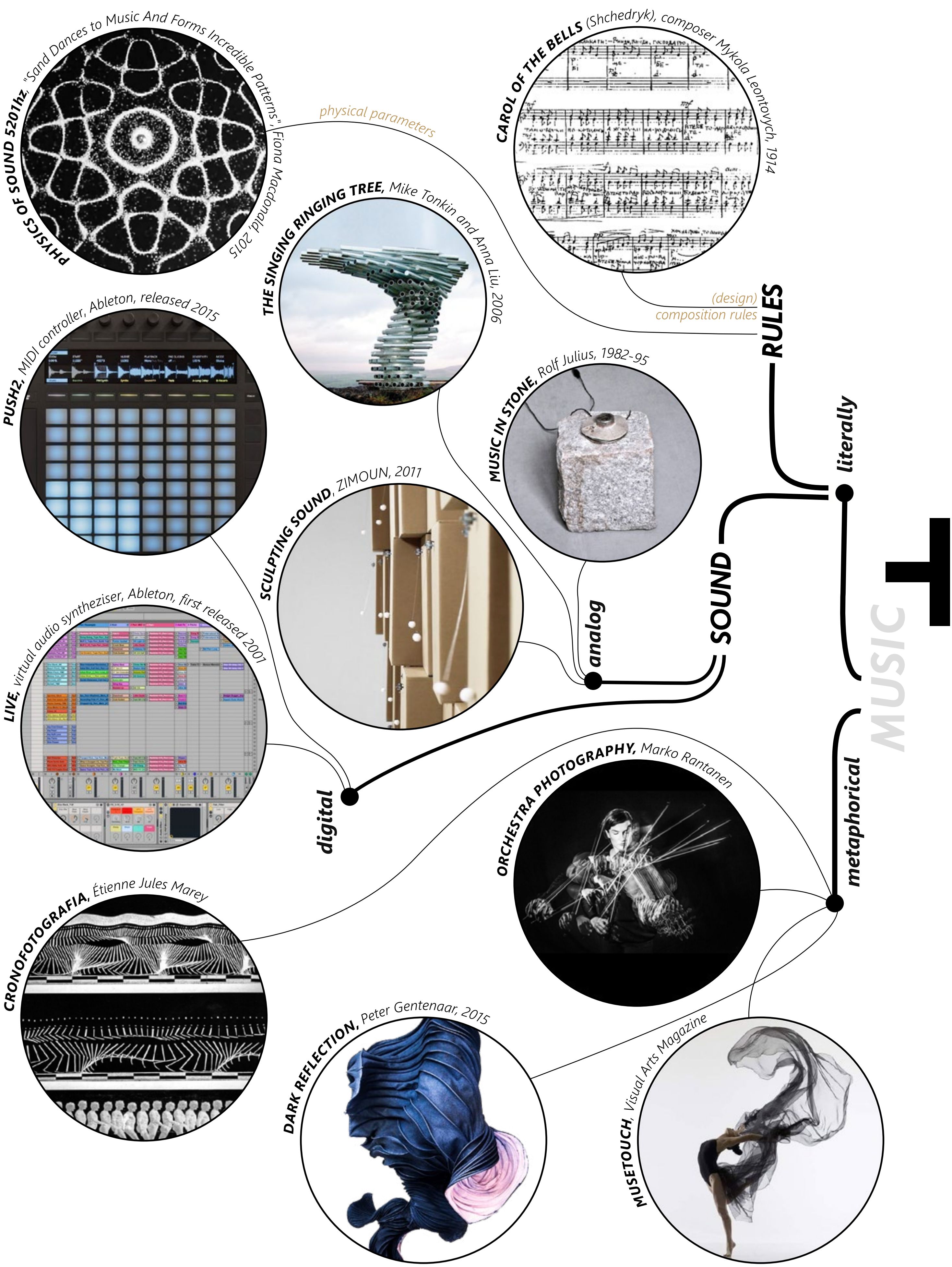
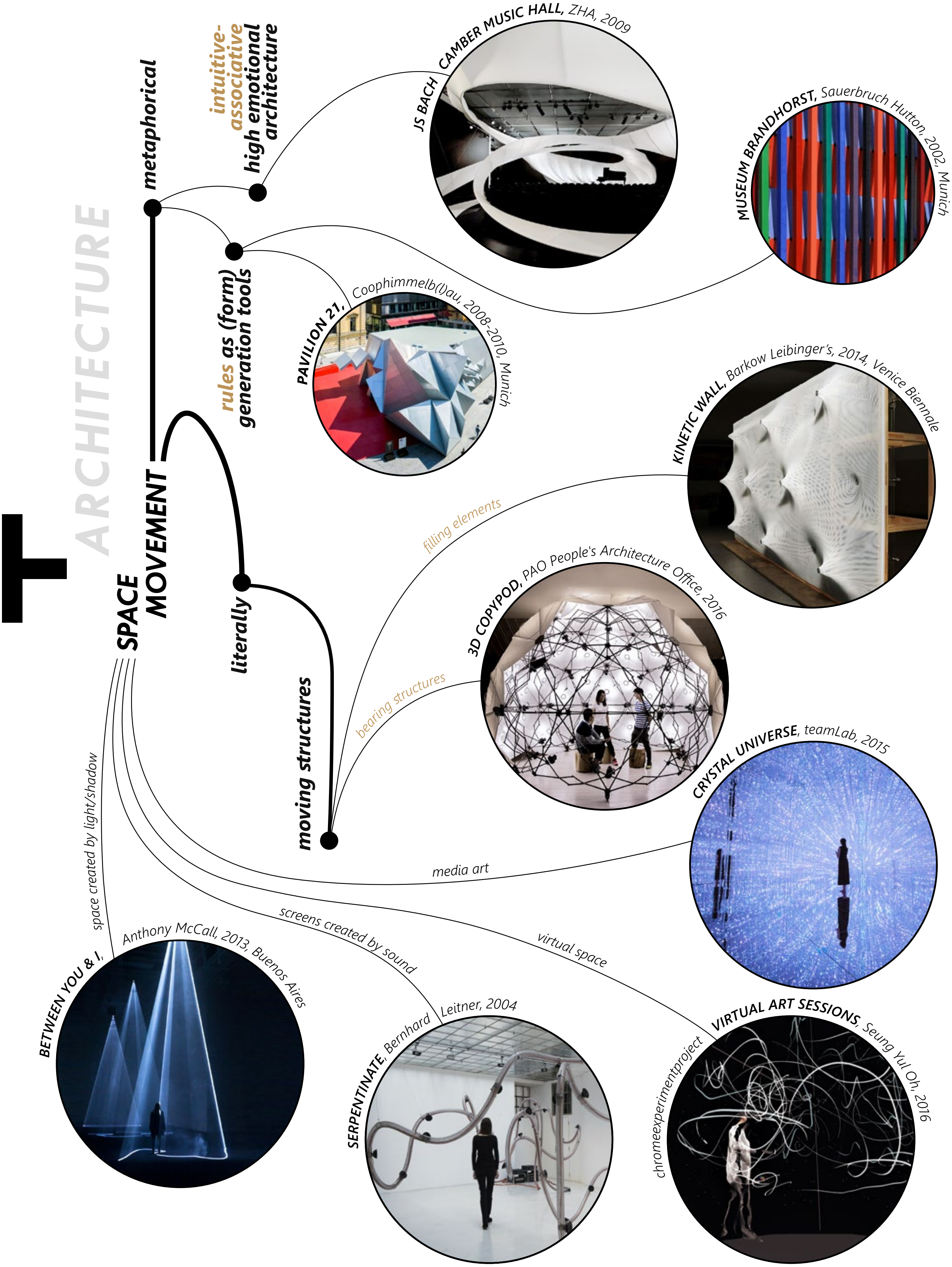


diagram I, ***"coordinate system"***


T
ARCHITECTURE
SPACE
MOVEMENT
metaphorical
intuitive-associative
high emotional architecture
JS BACH CAMBER MUSIC HALL, ZHA, 2009
rules as (form) generation tools
MUSEUM BRANDHORST, Sauerbruch Hutton, 2002, Munich
PAVILION 21, Coophimmelb(l)au, 2008-2010, Munich
literally
moving structures
filling elements
KINETIC WALL, Barkow Leibinger's, 2014, Venice Biennale
bearing structures
3D COPYPOD, PAO People's Architecture Office, 2016
media art
CRYSTAL UNIVERSE, teamLab, 2015
space created by light/shadow
BETWEEN YOU & I, Anthony McCall, 2013, Buenos Aires
screens created by sound
SERPENTINATE, Bernhard Leitner, 2004
virtual space
VIRTUAL ART SESSIONS, Seung Yul Oh, 2016
chromeexperimentproject

RESEARCH FIELD

Departing from the coordinate system described above, the main research fields to discuss in this work are movement, space, sound, and rules of their interaction.

PURPOSE

The starting point and the primary idea in this diploma is the idea of "unfrozen," shape variable architecture as a (re)presentation of musical and emotional flow. In this work, I research the possibilities and approaches of creating a real-time changeable space as an interactive pavilion, as an acoustic place for improvisation.

The most interesting question is: Can musical architecture be not only “frozen music,” as described by J. W. Goethe, but an “aleatoric” place, like aleatoric music, where some elements of composition (interactive parts) are left to the determination of behaviors of the visitors-performers), so the composition of form and music is determined by chance?

METHOD

The diploma is an experimental process of selection of the essential parameters, that are necessary for designing an interactive, space generates musical pavilion.

Form, place, materials, rules of interaction and control systems are gradually joining into one system: the Arcusticon pavilion. Tests of different approaches within the research fields mentioned above are necessary to find out, which one of them works better for achieving the main idea.

Therefore, using an empirical research method, the final design develops step by step.

MOVEMENT

MO

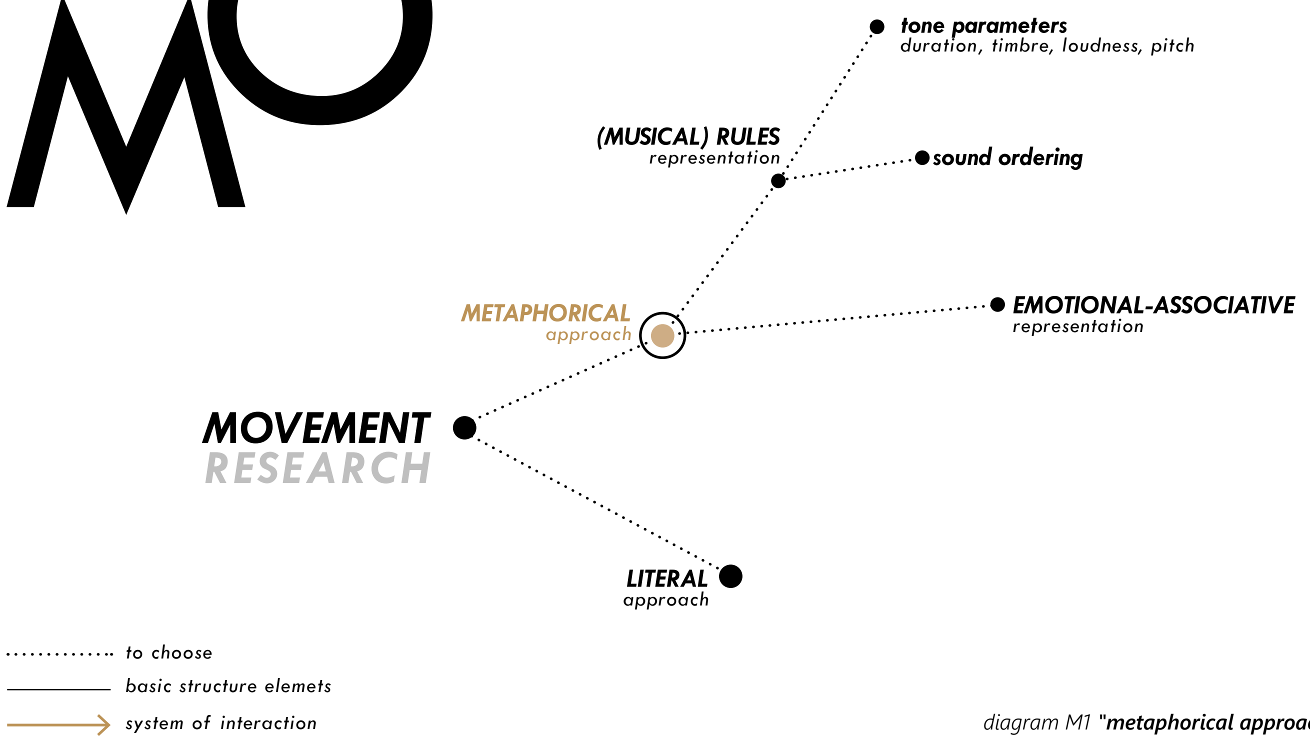


diagram M1 ***"metaphorical approach"***

Musical architecture, the main theme of this diploma, is seen as a combination of ***music + architeca ture,*** where the architectural part is represented through two elements: ***movement*** and ***space***. *(diagram M1)*

Musical architecture is based on comparing analog and similar methods of expression and impression in both architecture and music. In the most classical sense, ***music is*** about ***time*** and ***architecture is*** about ***space***.[1] Listening to music opens up stories about feelings, relationships, expressions of some ideas and emotions. In an analogous and synaesthetic way, the same can be "heard" with our eyes when observing the space around us. Listening to music can be about moving in space. Movement in architecture corresponds to the play button for the audio track. In this section of the diploma, thesis movement is considered as an expression tool in architecture.

This is my starting point for further research. I will consider two fundamentally different approaches in the interpretation of motion in a space: ***metaphorical*** and ***literal***.

METAPHORICAL APPROACH

This approach ***represents*** movement. We are talking about movement of the observer himself. It deals with his visual perception of an architectural space through a filter of subjective impressions. This allows architects to conduct an associative parallel between music and space.

There are two methods within this approach. The first one is a ***musical rules representation*** of different sound parameters in created space. A kind of "translator" converts, based on data, musical language into architectural language.

The second one is a creation of intuitive-associative, high emotional architecture as a representation of personal association ***(emotional-associative)*** with the help of melody, time, harmony, different emotions, etc. in space. This approach does not need rules and does not need translation from one data to another. It is more individual and very associative. *(diagram M1)*

(MUSICAL) RULES REPRESENTATION

This approach involves that the visitor of Arcousticon will read «encoded» data during his movement in space. In relationship with music, these data for designing architectural space are taken from ***tone*** (musical sounds) ***parameters*** or ***rules of musical order***.

Of course, even without knowing the "code" at the primary level of perception the influence on the observer will take place. Most visitors are able to recognize some fundamental idea or an emotional scenario when walking through a building. However, at a deeper level of visual reading, the identification and interpretation of certain rules used in the author's conceptual framing of the intended building, allows us to see different spaces with deeper

1 Lessing, Gotthold Ephraim, 1994 [1766], "Laokoon oder über die Grenzen der Mahlerei und Poesie", Stuttgart: Reclam

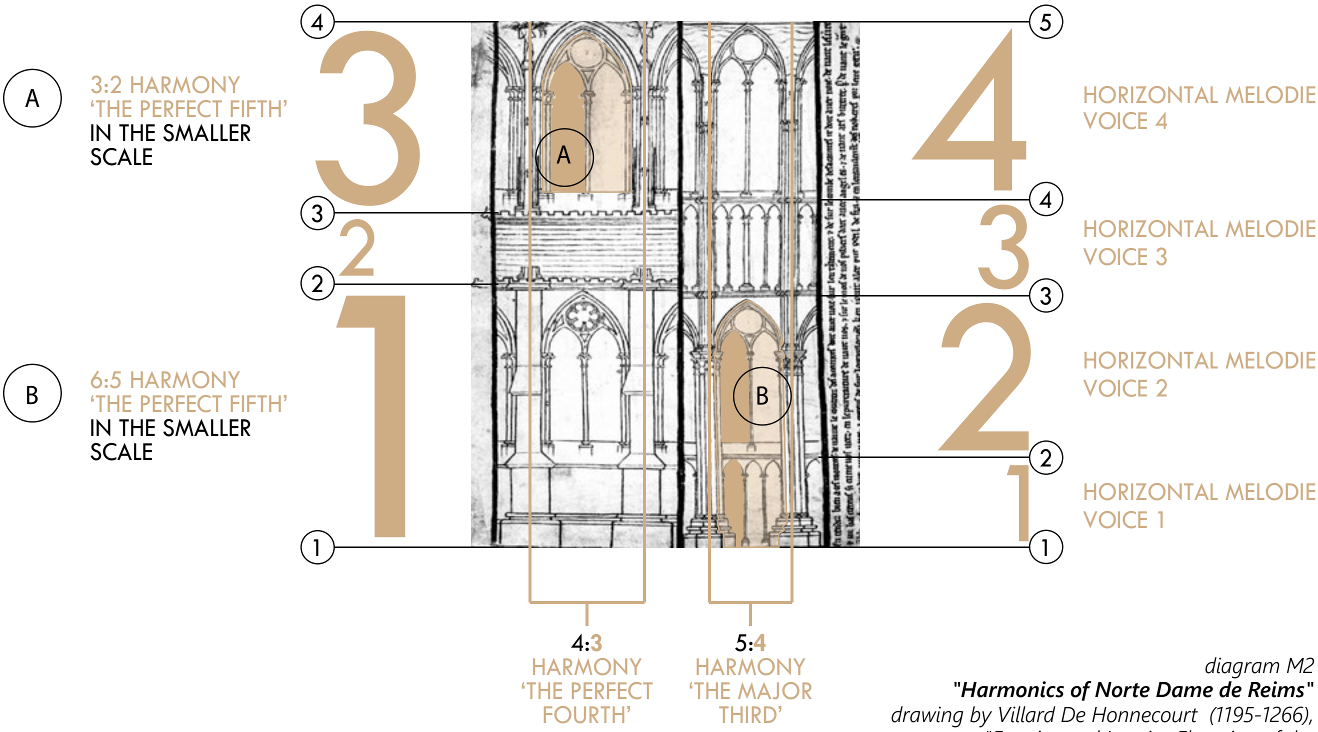


diagram M2
"Harmonics of Norte Dame de Reims"
drawing by Villard De Honnecourt (1195-1266), "Exterior and Interior Elevation of the Lateral Walls of Reims Cathedral"

meanings.

To be able to read these conceptual intentions, there must exist some perceptible cues in the physical setting of the particular building.

One layer of such perceptible cues is since long known as proportion, first in music, later in architecture. At least at the antique period, architects actively began to use this method, particularly for the construction of sacred buildings usually based on rituals.

The resulting movement was choreographed and had to reveal a certain ripple, harmony, and a desire to convey some deeper veracity to the observer. All this was interwoven with the idea of a universal ***«sacred*** (divine) ***code»***, as – on a more local level - a kind of bridge between architecture and music and - on a more global level - between heaven and earth.

This symbiosis led to evaluations of the experienced in a more significant, transcendental and eternal direction.
The *diagram M2* depicts how this approach was used in the Reims Cathedral.

The value was brought not only by using regularities in proportions for specific compositional spatial solutions but also by the system of ordering specific architectural forms. Architects borrowed this system from music by reflecting the usual concepts of writing a musical composition. This approach allows to develop a motion scenario and to control the intensity of the intended «melody». In this way, architecture can bring some melody into the physically static and immovable building.

European composer Pérotin, and the musicians of Notre Dame work in Paris 12-13th century. They *«loved the architectural polyphony, and even outperformed it. Their experiments with four voices and simultaneous clusters of chords are more complex than the nave elevation and much cheaper to build in music than stone. They emphasized harmonic ratios such as 3:2 (called with explicit Godly overtones, 'the Perfect Fifth') 4:3 ('the Perfect Fourth') and ever more subtle harmonic relationships of 5:4 ('the Major Third').» «These often moved in great blocks creating harmonic chords pleasing to the ear. Architects are stacking three or four levels (arcade, triforium, gallery, clerestory) in equivalent chords pleasing to the eye.» «The five horizontal lines of musical notation – the staff – and their four spaces between are roughly like the parallel horizontal 'melodies' of the four-part nave elevation, reading left to right as one approaches the altar: except the musical melodies cross the five lines, while the 'chords' of architecture stay mostly locked between the string courses.» «Olso rhythms are marked in several ways, such as the engaged colonnette on every second pier.» «Each of these horizontal areas can be seen as a different choral voice.»*

Charles Jencks 2013
"Architecture Becomes Music"

photo M1
The crossing of two axis: axis of the holocaust and axis of exile. Jewish Museum in Berlin, Daniel Libeskind 2001, photo by Bitter Bredt

photo M2
Holocaust tower. Jewish Museum in Berlin, Daniel Libeskind 2001, photo by Bitter Bredt

photo M3
Garden of exile. Jewish Museum in Berlin, Daniel Libeskind 2001, photo by Michele Nastasi

EMOTIONAL-ASSOCIATIVE REPRESENTATION

This approach is intended primarily to immerse an observer in a particular emotional setting of space by appealing to instinctively intuitive associations. It is used, for example, in museums, interactive spaces or exhibition buildings.

It is more likely to emotionally stimulate the interest of an observer for certain cultural-historical phenomenons. With the aid of scenography, the observer is induced to raise questions about his own experiences. While walking through the building he is actively performing the scenes and can go deeper into the topic, after its completion.

A convincing example of this approach is the Jewish Museum Berlin by architect Daniel Libeskind in 2001.

According to Libeskind[1] the real inspiration for the building was Walter Benjamin's book "Einbahnstrasse"[2] (one-way street) and Schoenberg opera "Moses and Aaron"[3] a work in three acts with no music beyond the end of the second act. Libeskind wanted his building to be a prolongation of this unfinished musical work. To show that he was serious he wrote his proposal on the staves of a musical score and entitled it "Between the lines".

In this project, Daniel Libeskind created a pulsating space that sometimes gives a feeling of melancholy, sometimes feeling of fear.

«The zigzag path one walks on is set against the Holocaust void one cannot enter but always cross; the slashes and cuts in the exterior grey zinc contrast with the tilt of the white concrete stumps (out of which willows emerge wafting a peaceful note). Oppressive concrete walls set off liberating views of the sky, and so on through the play of violent diagonals versus a background of neutral grey. Libeskind, a trained musician, who has designed a series of architectural Choral Works, is obviously sensitive to analogies between the two fields.»

«For instance, his long thin stairway, punctured by angular struts and underscored by dark stone, is a natural echo of the mood created in Albinoni's Adagio in the key of G minor. This has a descending base-line that repeats again and again – 'going down, going down' as it were – a naturally expressive form of sadness, as stereotyped as using a minor key in the context of death.»

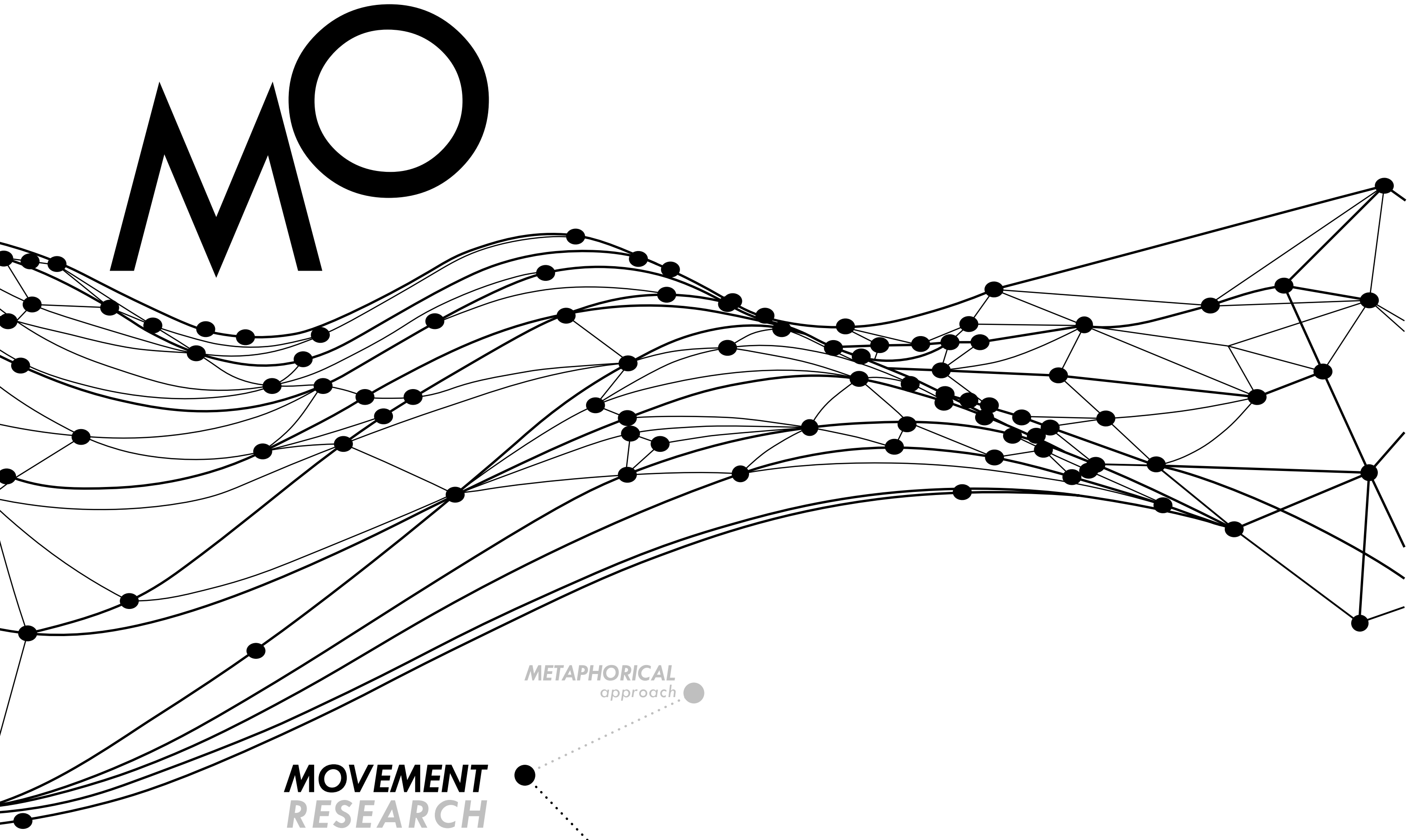
Charles Jencks 2013
"Architecture Becomes Music"

1 Libeskind, Daniel (2002): interviewed for film of Stan Neumann and Richard Copans (2002): Le Musee Juif de Berlin entre les lignes

2 Benjamin, Walter (2001 [1928]): Die Einbahnstraße, Frankfurt a. Main: Suhrkamp

3 Schoenberg, Arnold (1957 [1932]): Moses and Aaron, Zurich: Opera House

photo M4 Jewish Museum in Berlin, Daniel Libeskind 2001, photo by Laurian Ghinitoiu

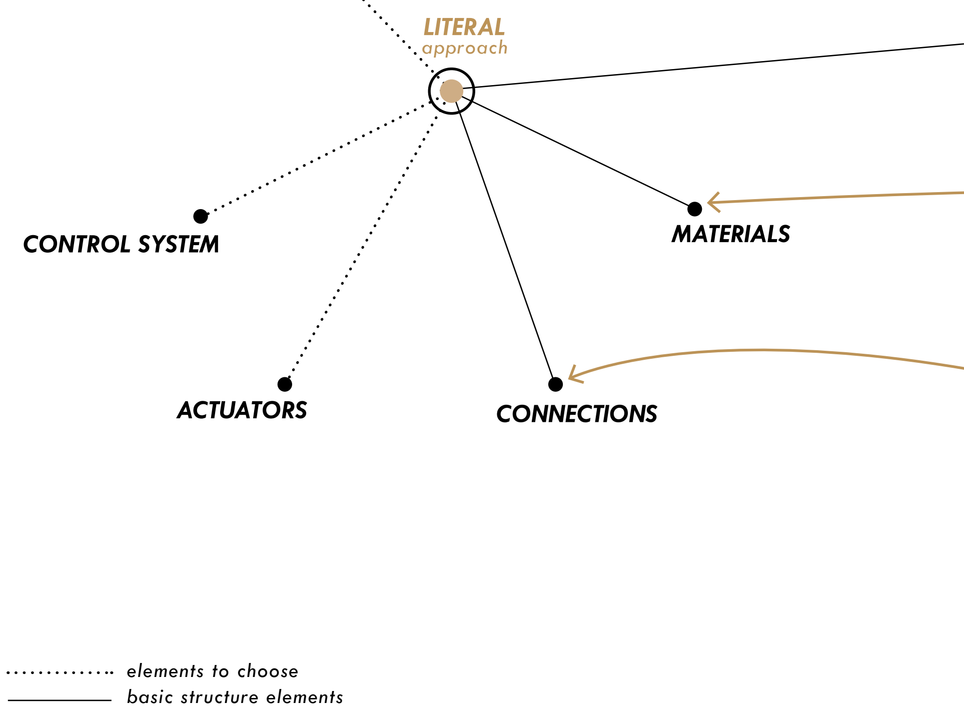


LITERAL

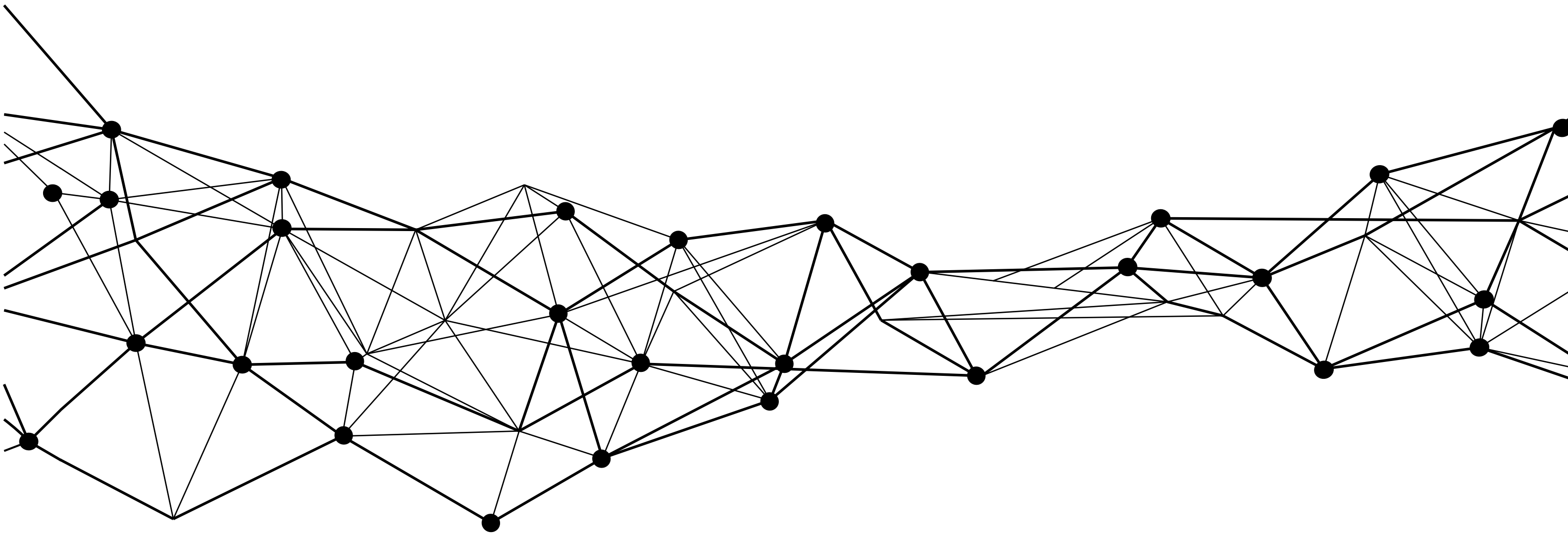
The literal approach means a literal movement in space for ***presenting movement.***

"The aesthetic presentations of moving objects, of dynamic processes or structures that unfold their effect on the surrounding space in front of the eye of the beholder."[1]

Diagram M3 shows 5 structural parts that are needed to work with a literal approach: ***structures*** (type of parts to be moved), ***materials*** (physical characteristics of this parts), ***connections*** (between each other), ***actuators*** (power-driven machines that convert energy into mechanical work) and a ***control system*** (measure and control of automatic processes).



1 Vogt M., Schaeffer O., Schumacher M., (2010 [2009]): Move, Basel, p. 22



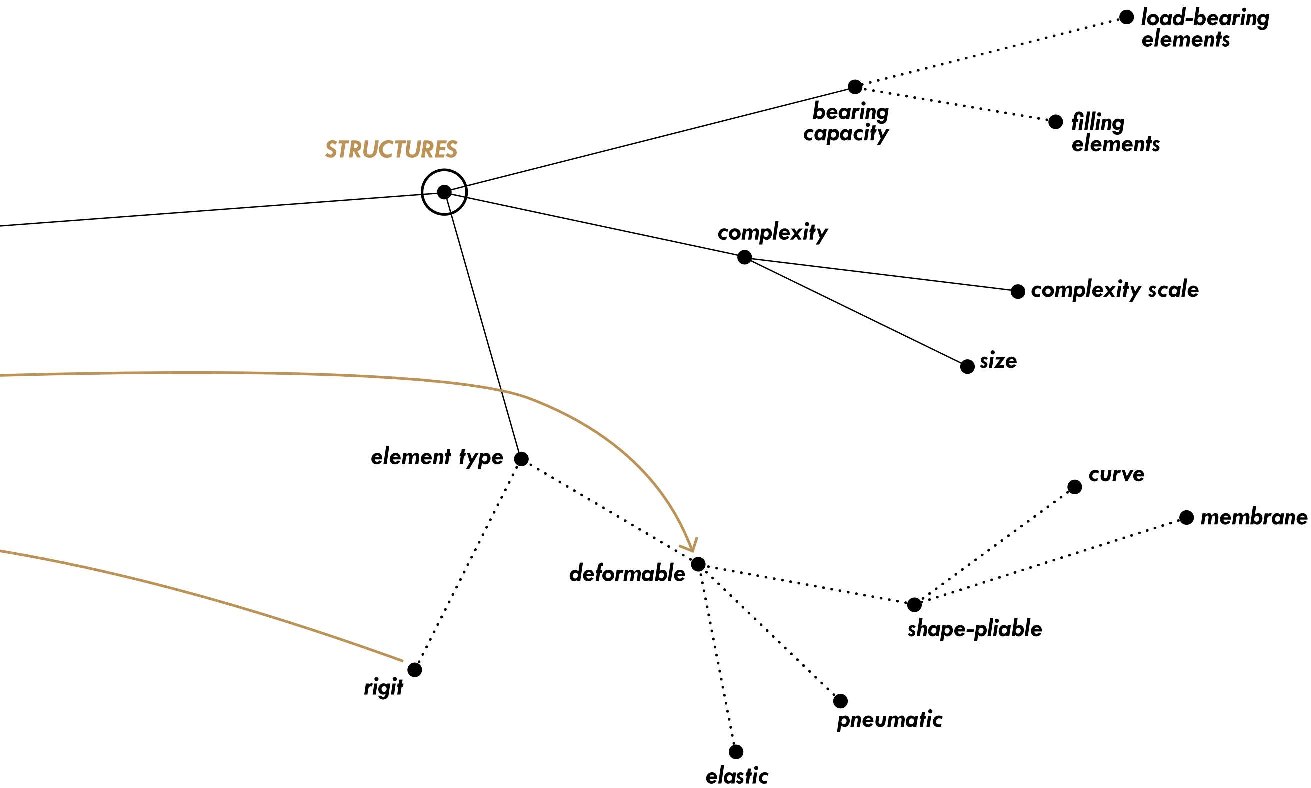
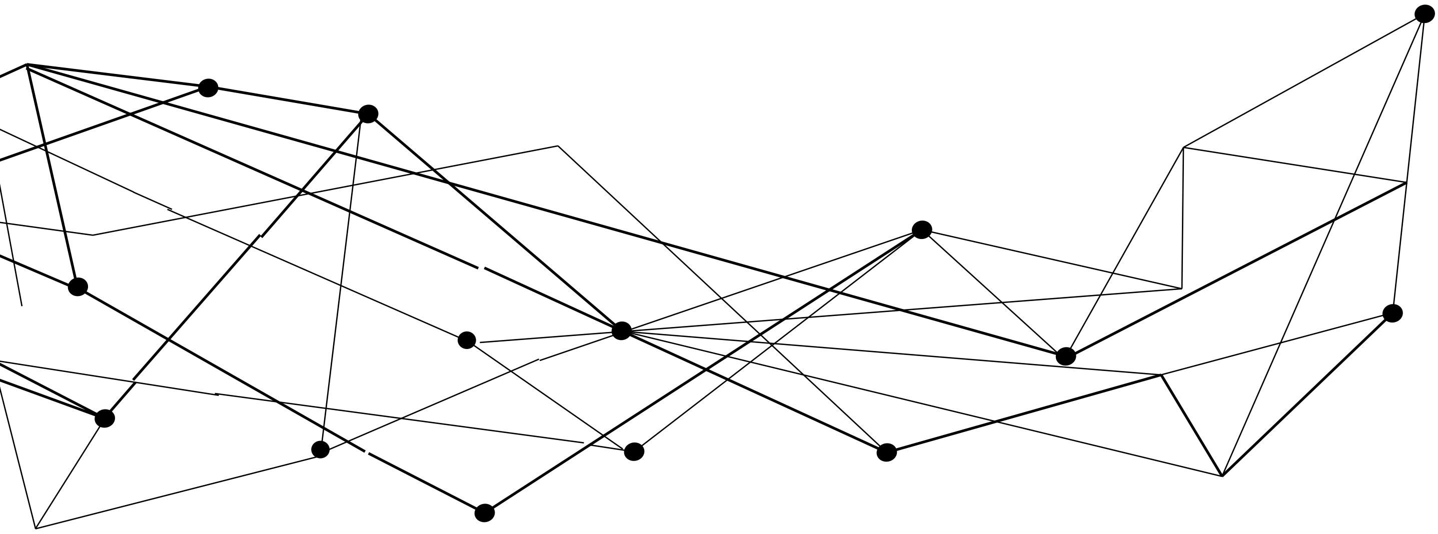


diagram M3 "**literal approach**"



STRUCTURES

This section considers moving elements as far as their complexity and scale in concerned. By complexity is meant a type of system that is built of many parts with their static and bearing capacities. Scale determines how large this parts or the whole structure of this parts is going to be.[1]

1 Vogt M., Schaeffer O., Schumacher M., (2010 [2009]): Move, Basel, pp. 40-43

bearing capacity

The movable elements are divided into two types: as a load-bearing structure and as filling structure. The main difference between them is seen in the scale of proportions.

movable load-bearing structure

It concerns the change of the local positions of all of the structural elements during movement in the space. A ***Simple*** bearing structure can be seen on *photo M5*. In this project of a privat home, some rooms can be rotated. In comparison to the scale of whole house, these movablee volumes don't have any bearing funktion, but compared to the scale of one room they do. The position of the whole room is changeing in the space during movement.

Another type of bearing structures is a more ***complex*** system. It can seen on *photo M8*. This kinetic animal by

photo M5, "Sharifi-ha House", Next Office 2013, photo by Parham Taghioff

photo M6, townhouse in the West Village, BWArchitects 2013, photo by BWArchitects

photo M7, SDU University of Southern Denmark Campus Kolding, Orbicon 2014, photo by Hufton + Crow

Theo Jansen is made of variety of elements that are working together to generate movement. Complex changement of positions of one single element triggers complex movement in neighbouring elements and so on. We are using systems like that in architecture when we need expanding and deployable structures, for example the Rolling Bridge by Heatherwick Studio, London 2004 or Hoberman Arch by Hoberman Associates, USA 2002.

movable filling elements

They are a functional but not a load-bearing part of the structure. Usually, they are designed as surfaces for sun and wind protection, or for a spatial separation, or as facade systems. They can be also organized in a simple or complex manner.

A ***Simple*** system can be seen on *photo M6 and M7.* Windows or sunblinds can be opened separately, without opening other elements. Their movement does not influence other parts.

On *photo M9* is presented a ***complex*** system as a surface that reacts on movement and functions as a representation of it. By this system one part is connected to another one and so movement is reflected on a whole surface of the structure.

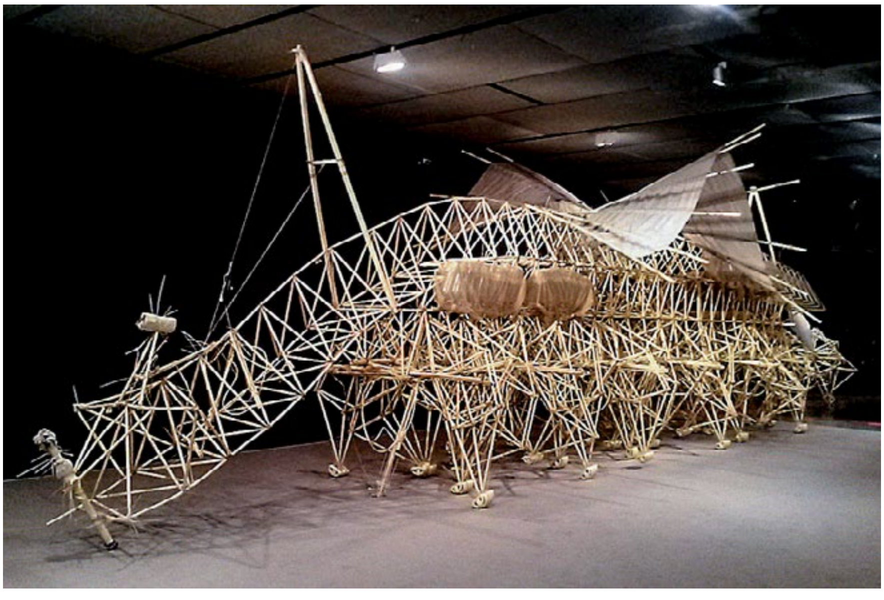


photo M8, "Animaris Modularius", Theo Jansen 2016, photo by Theo Jansen

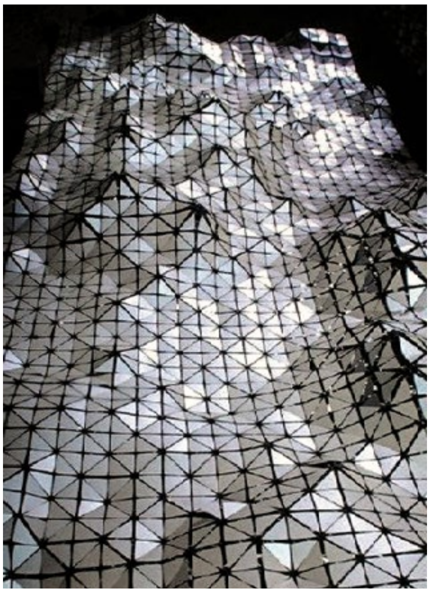
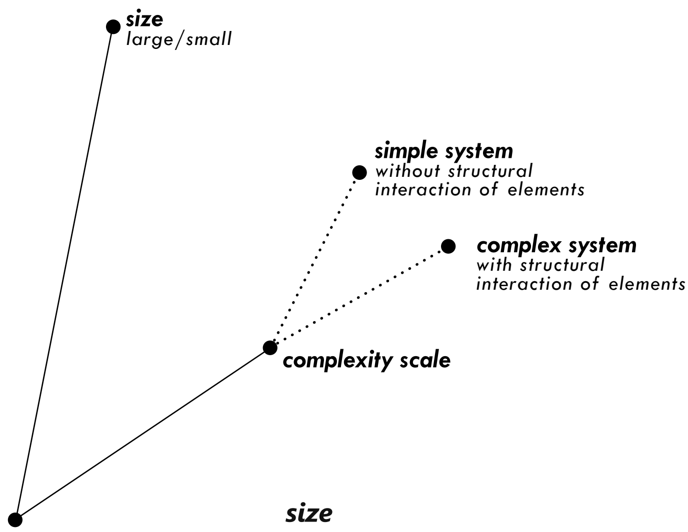


photo M9, Aegis Hyposurface, dECOi and Mark Goulthorpe 2003-2004, photo by Sursa

photo M10, "Garden House," Caspar Schols, 2016.
Photo by Jorrit't Hoen

diagram M4 "**scale**"



complexity

The scale of structures can be seen as an actual scale of proportions of the movable parts, but also as a complex system depending on the logical hierarchy of movable elements, there necessary, control systems and the quantity of the parts.

size

The photos above are showing different scales of load-bearing movable structures. The structures, that can be seen on *photo M10*, are simple structures but with large size.

The external and internal frames of the house can be displaced in one axis, thereby opening or closing the space.

The next example is a 3d scanning booth as a complex moveable system (expanding system) but with a medium-size. The structure allows to change the scale of inner space for scanning larger or smaller objects more precise and with better

photo M11, "3D scanning booth," people's industrial design 2017. Photo by people's industrial design

photo M12, "softwall" + "softblock modular system," molo design 2010. Photo by molo design

quality. *Photo M12* shows moveable wall constructions that enable the zoning of space. It is very lightweight, at the same time load-bearing and can change position in space very easily. It is a complex system with a smaller size.

complexity scale

Complexity-scale is a parameter, that describes how simple or complex the system is depending on the number of movable elements in it and the quantities of their interaction levels for technical support. It is necessary to have a system of control (data analysis and response) and actuators. The "3d scanning booth" an "softwall" projects, for example, have a complex scale because of a complicated system of their structural elements.

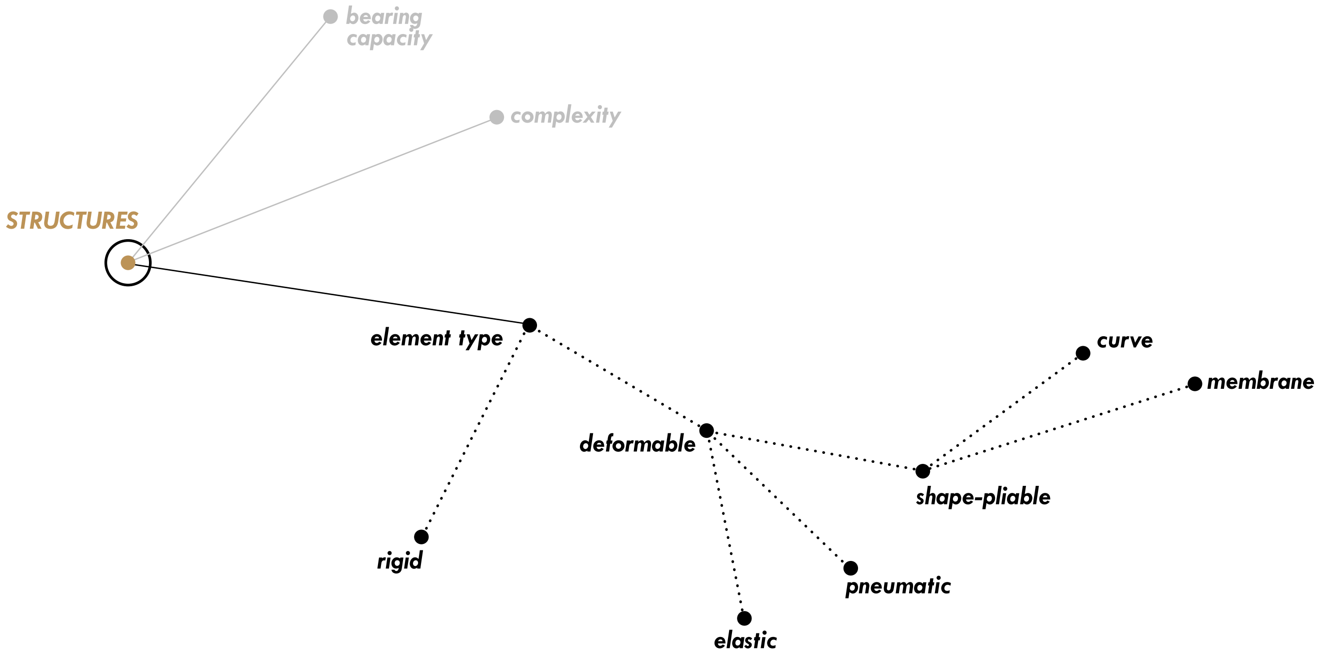


diagram M5 ***"elements type"***

element type

This is a third parameter needed to define the movable structures and to characterize the physical parameters of the constituent elements in a context of movement. There are two groups of elements: ***rigid*** and ***deformable*** ones.

rigid body elements

Movement is only possible in two main mechanical movement types: translation or/and rotation. Both movement types allow to use three possible vectors of degrees[1] of freedom. *See diagram M6, M7*. To be moved rigid body elements need a ***movable connection***, that will allow the movement in the space. The second important parameter is the ***dimension*** of this elements, 2-dimensional (line or surface) or 3-dimensional (volume). 2-dimensional elements are generally smaller and lighter and needed lower energy sources and actuators power to be moved. *Diagram M8*

1 "Statisticians use the terms "degrees of freedom" to describe the number of values in the final calculation of a statistic that are free to vary." Hoffman, Howard S., Internet glossary of statical terms: degrees of freedom, https://www.animatedsoftware.com/statglos/ statglos.htm#-degrees_of_freedom, last view: 28.10.2018

deformable elements

Unlike rigid body elements, deformable elements ***do not need the movable connections*** because their movement in space is carried out by the transformation of their bodies. This is possible due to the peculiarities of their material.

They are three different types of deformable elements: ***elastic, pneumatic*** and ***shape-pliable***.

Deformable elements, as well as rigid elements, can be characterized by movement types and dimensional parameters. *See Diagram M9*

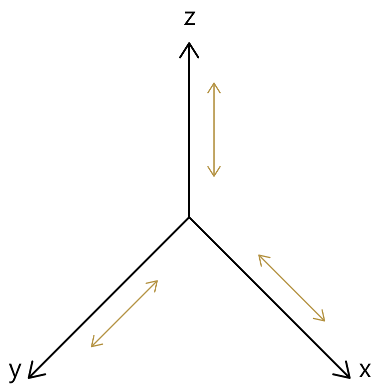


diagram M6 ***"translation"****,*
three degrees of freedom

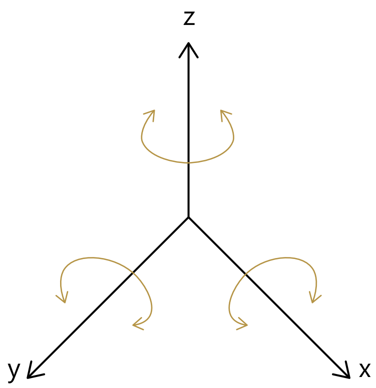


diagram M7 ***"rotation"****,*
three degrees of freedom

photo M13 ***shape-pliable surface***, *Kinetic Wall, B.Leibinger 2014.*
photo by J. Foerster

photo M14, Kinetic Wall, B.Leibinger 2014
photo by J. Foerster

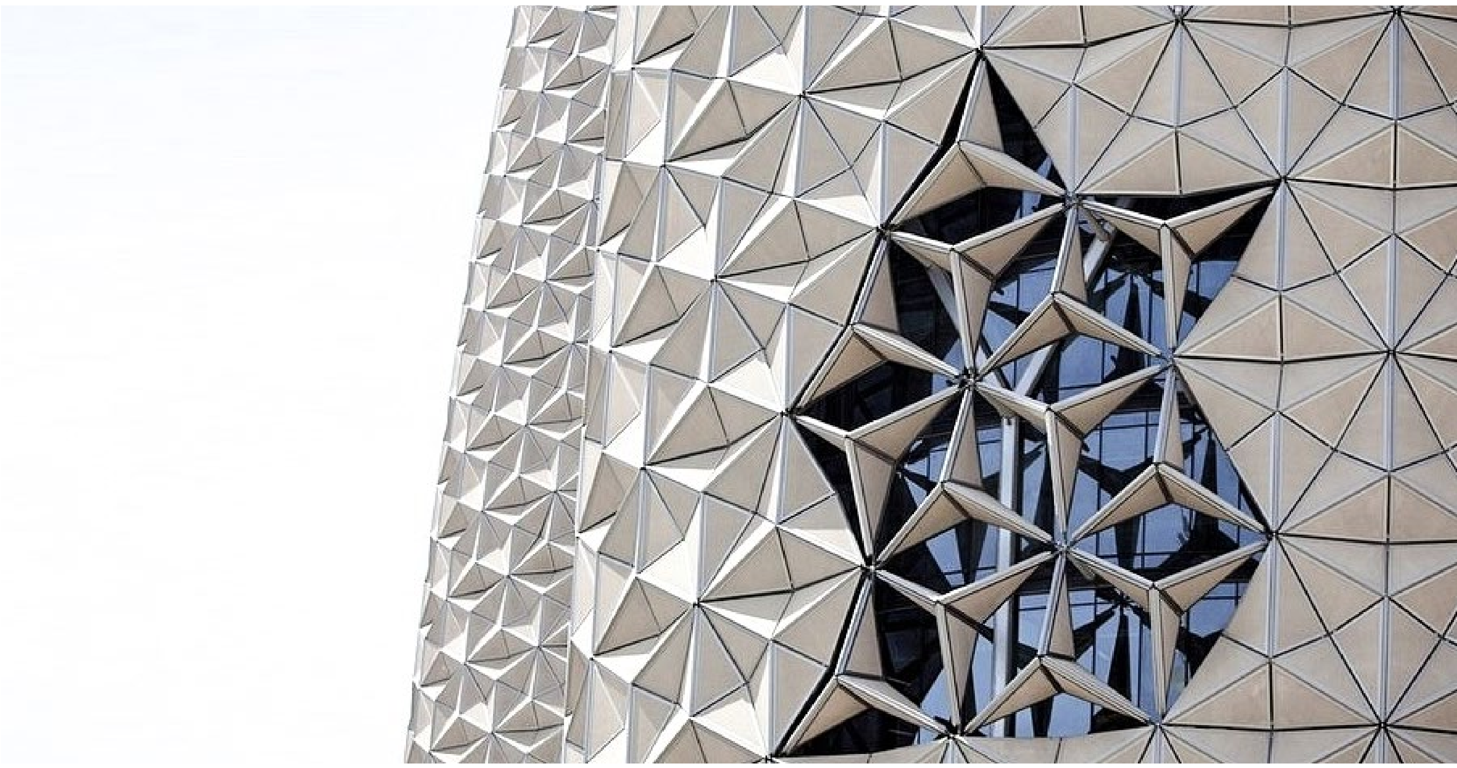
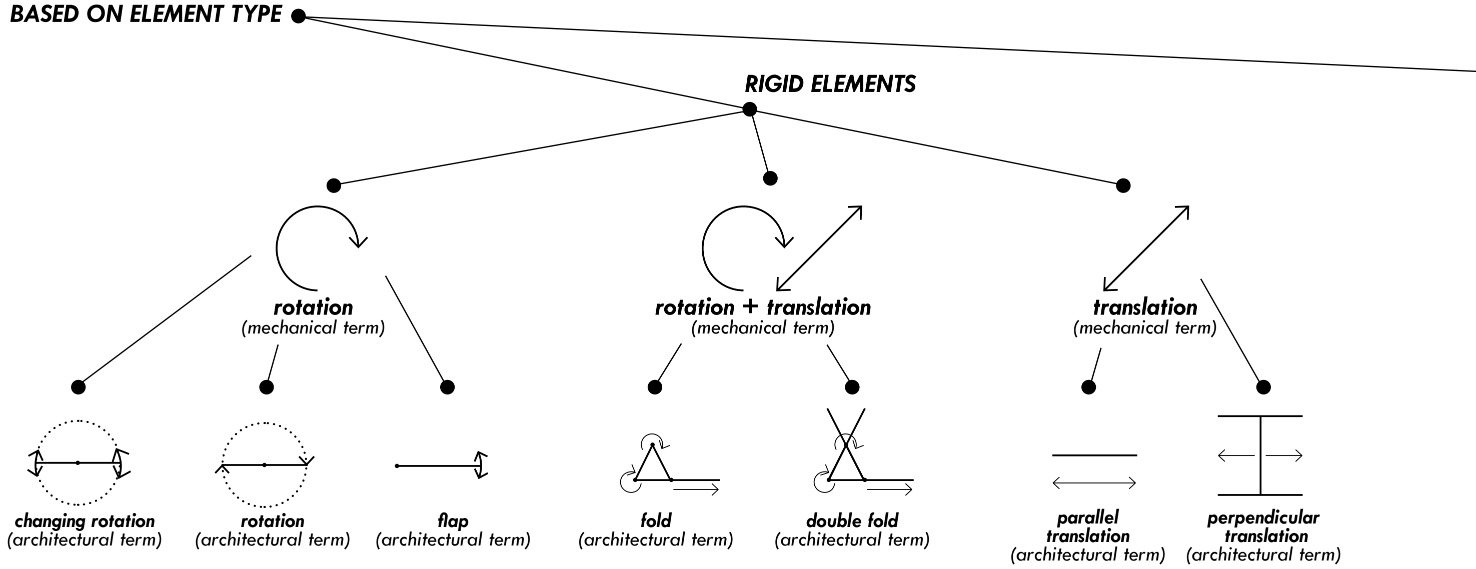
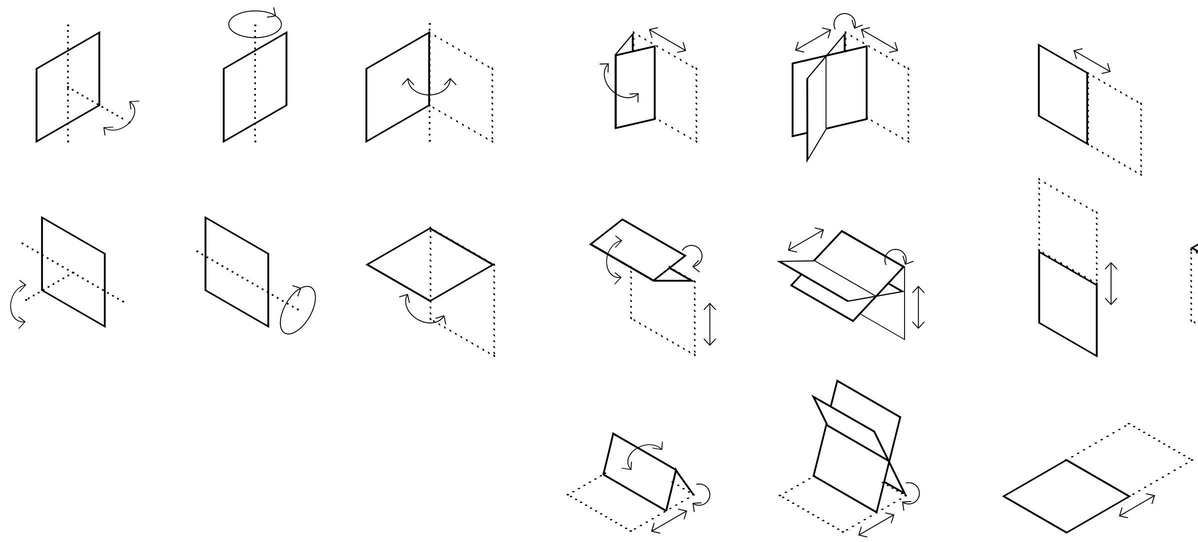


*photo M15 "**rigit body structure**", responsive facade Al Bahar Towers, Aedas Architects 2012*
photo by budavartours.hu

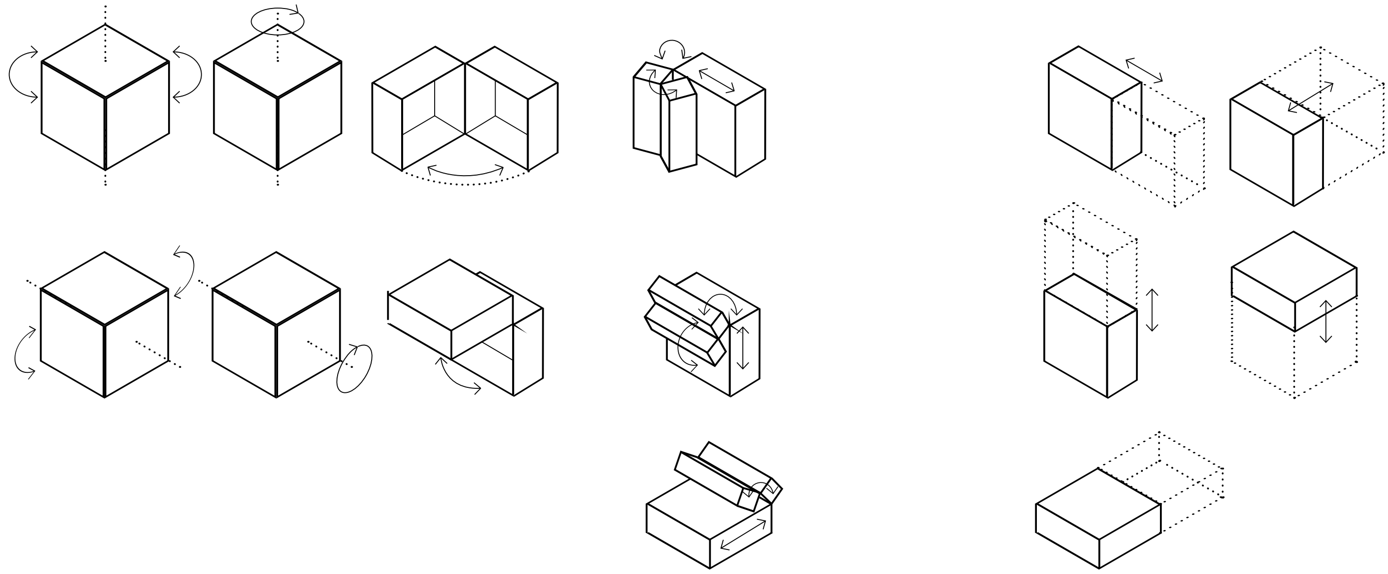
MOVEMENT TOPOLOGY BASED ON ELEMENT TYPE



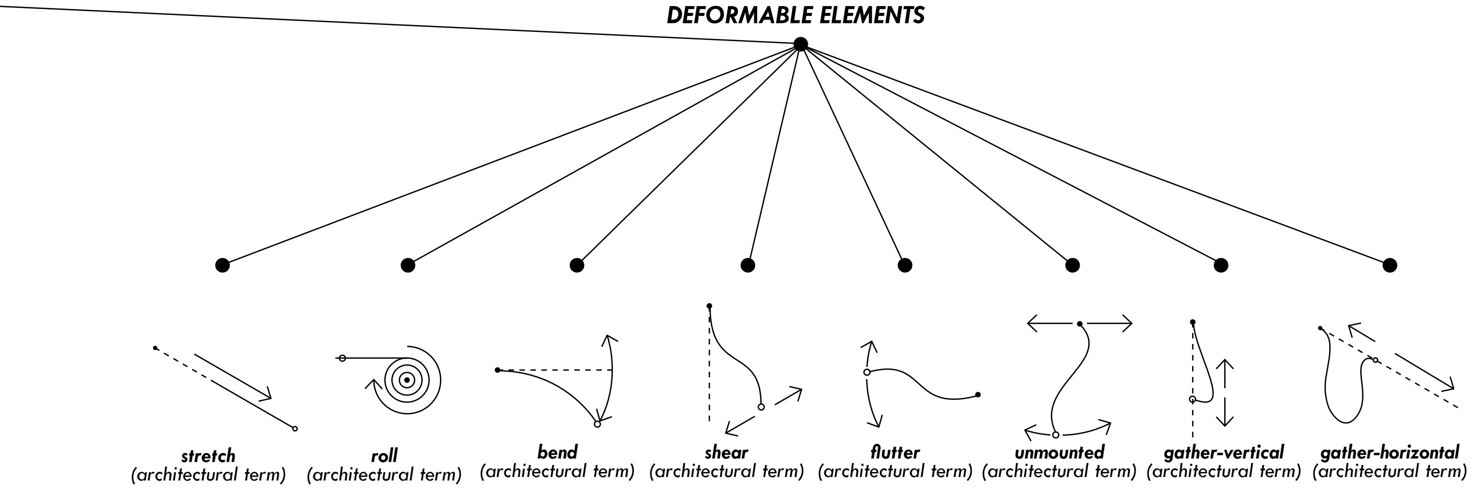
2D ELEMENTS



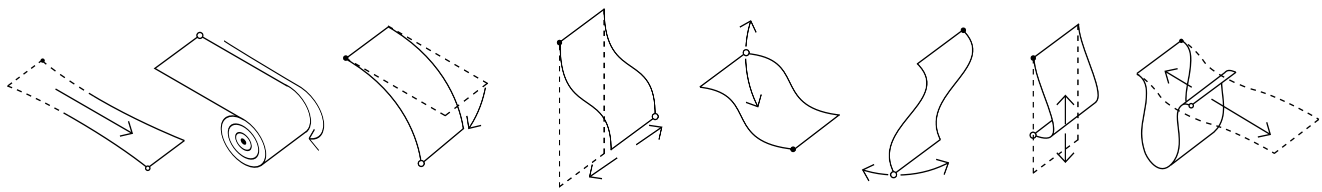
3D ELEMENTS



DEFORMABLE ELEMENTS



2D ELEMENTS



3D ELEMENTS

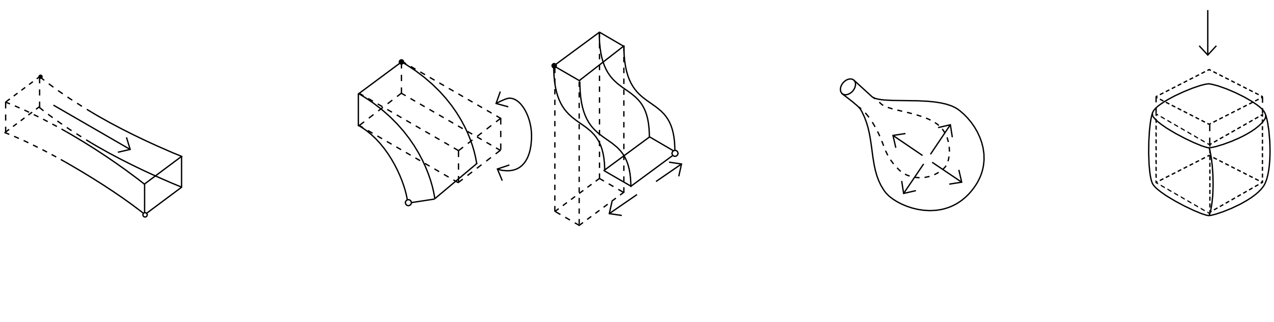


diagram M8 ***"movement topology of different element types"***,
based on diagram "movement topology", by Michael-Marcus Vogt, OliMichael-Marcus Vogt, Oliver Schaeffer, Michael Schumacher, 2010, "Move"

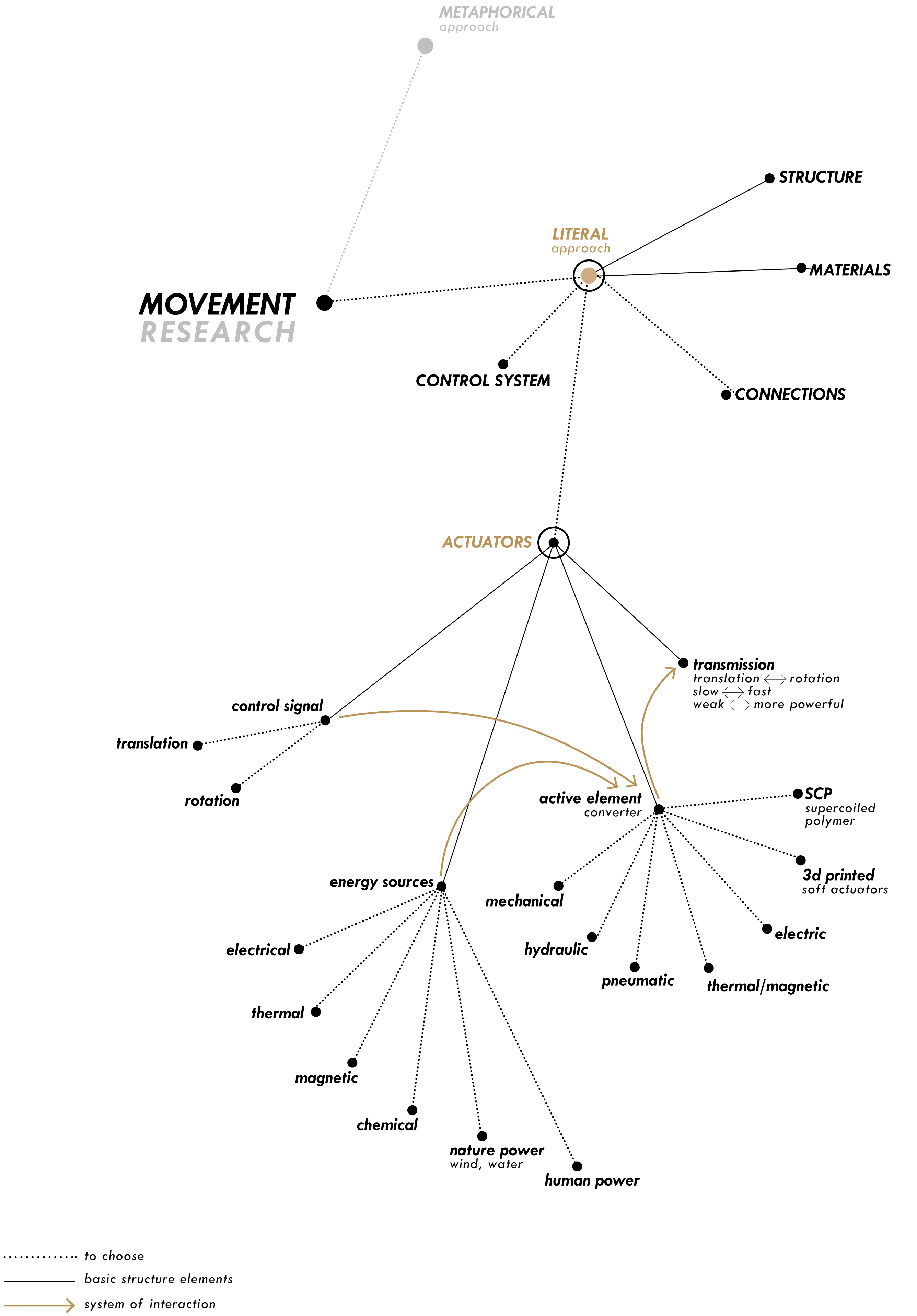


diagram M9 "**actuators**"

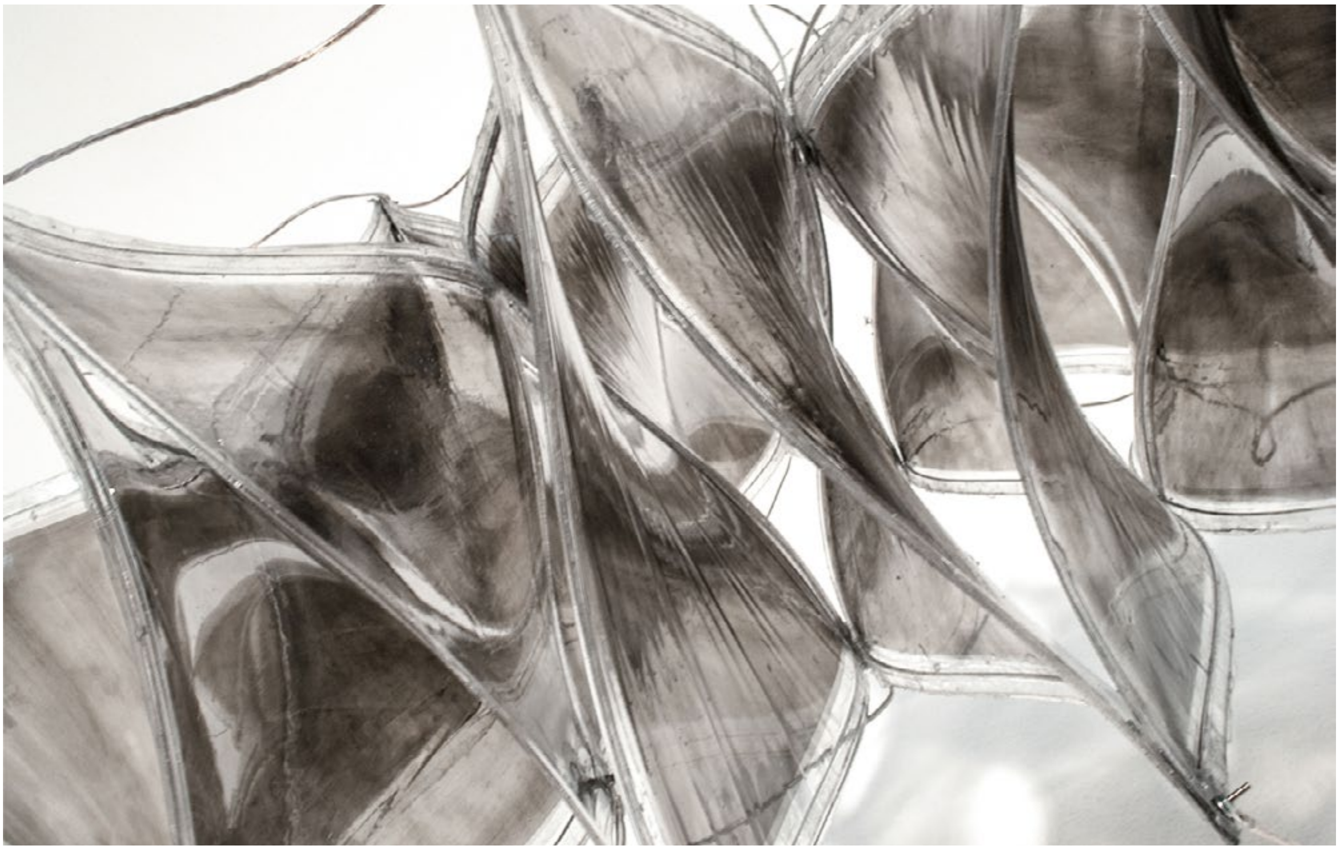


*photo M16 "**soft actuaror from electroactive polymers**",*
"ShapeShift", E. Augustynowicz, S. Georgakopoulou, D. Rossi, S. Sixt, 2010

ACTUATORS

These are devices that convert one kind of energy (electrical, magnetic, thermal, chemical) into another (usually into a mechanical one). This leads to the performance of an individual action specified by the control signal.[1] It is responsible for moving or controlling a mechanism or system and requires a ***control signal*** and a ***source of energy***.

Diagram M9 shows the main types of actuators and their energy sources.

1 Wikipedia, (last edited 2018): Actuator, https://en.wikipedia.org/wiki/Actuator, last view: 28.10.2018

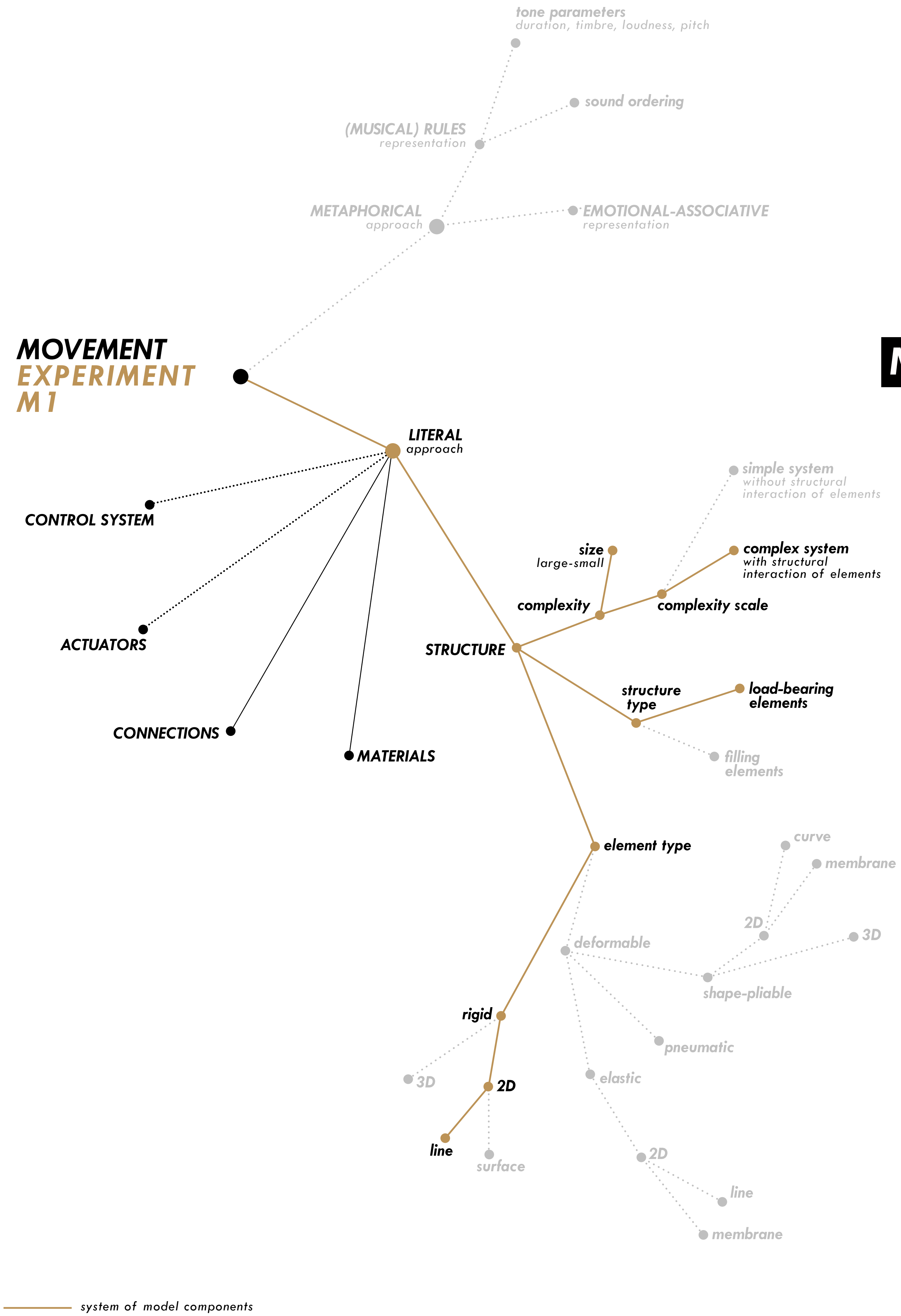


photo on the left side
© Tetyana Vovk, 2018 "ARCOUSTICON"

diagram M10 ***"experiment model M1"***

This experiment was necessary to understand, which parameters are important for a ***complex bearing moveable structure*** and to understand it's movability.
See Diagram M10

The size of this pavilion structure measures 4mx4mx4m, a middle size necessary for spatial differentiation of rooms. The physical model itself is made in the scale 1:30.

The structure itself is composed of 2-dimensional rigid body elements forming triangles. This primary element is very static to work with and allows playable form variation as a structural part.

Triangles are connected with each other with movable connections or hinges. As we can see in *diagram M11* below, each side of a triangle can be used as a rotation degree of freedom. In the *experiment model M1* I use 2/3 sides for movable joins, so every structural part (triangle) has 2 degrees of freedom.

The pavilion consist of 12 triangles joined with each other. They form one large complex loop system, able to be closed or opened. *Diagram M12* shows this connection and the number of degrees of freedom in a whole structure, that ensure the possibilities of movement.

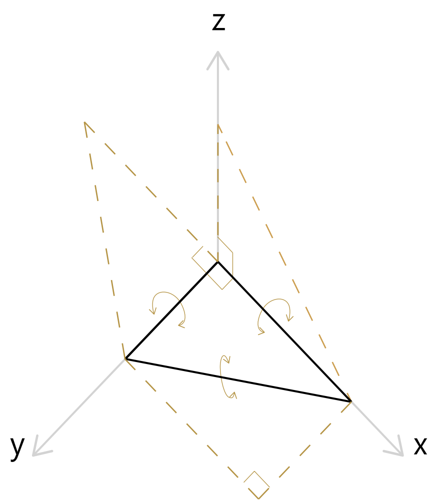
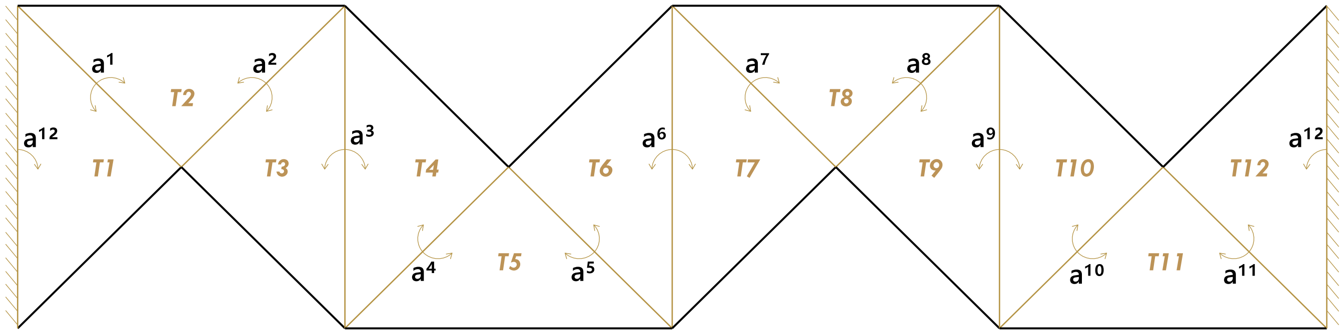


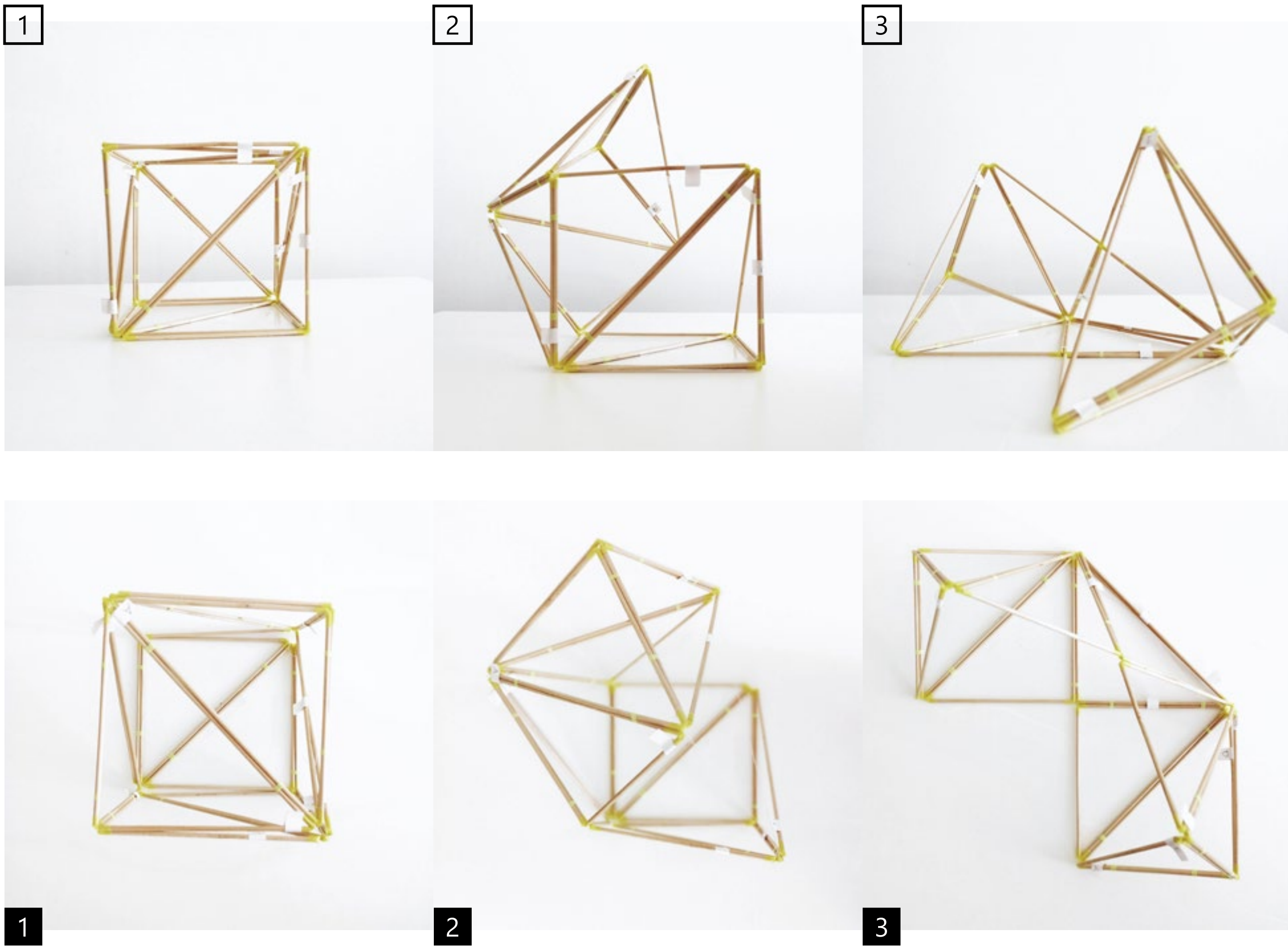
diagram M11,
"possible degrees of freedom"



a^n - *degrees of freedom*
rotation along the triangle side axis
(in each triangle of 2 of 3 of its ribs are involved)

T - *triangle, or basig bearion structural body to move*

diagram M12
"possible degrees of freedom"



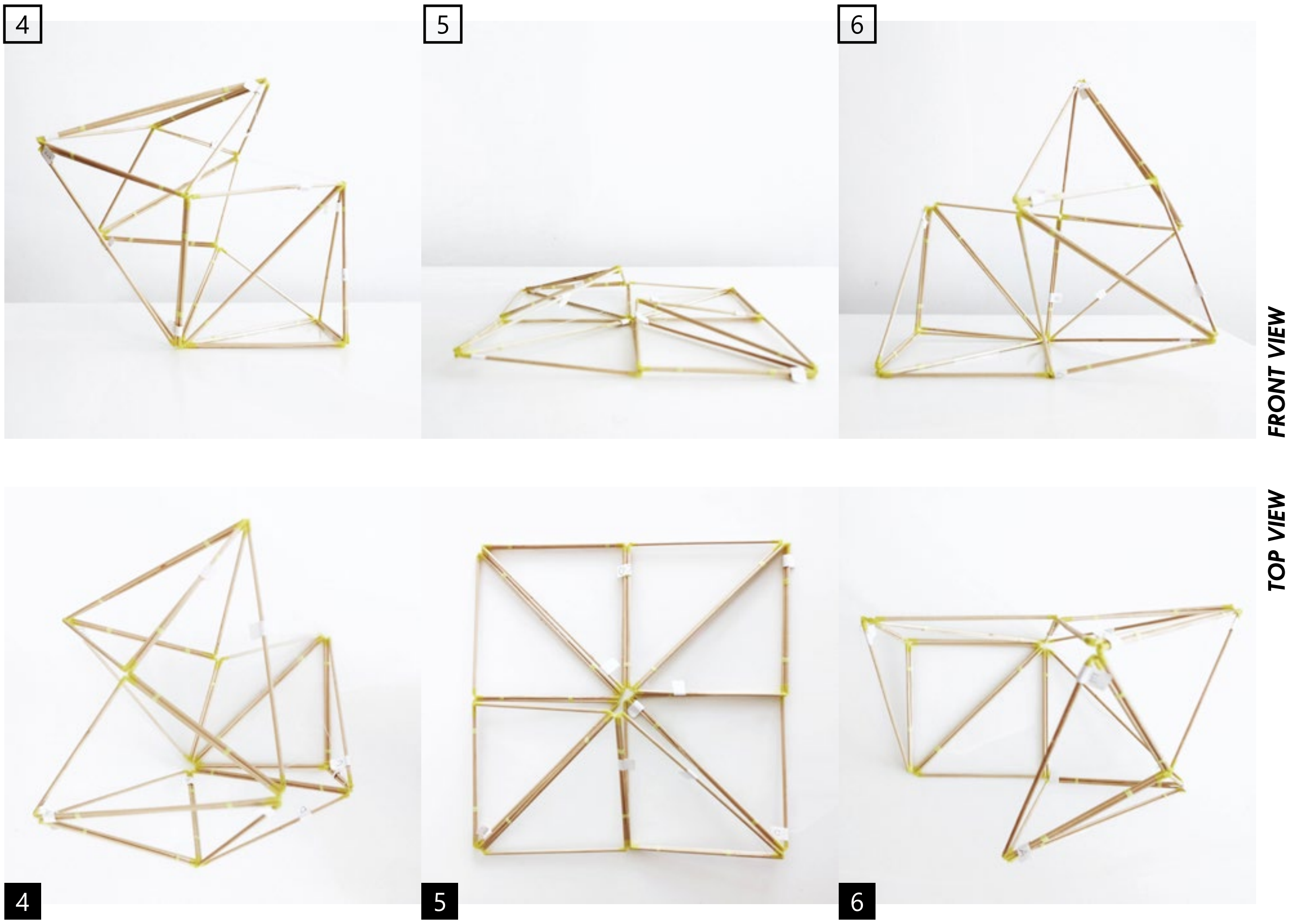
FRONT VIEW

TOP VIEW

1

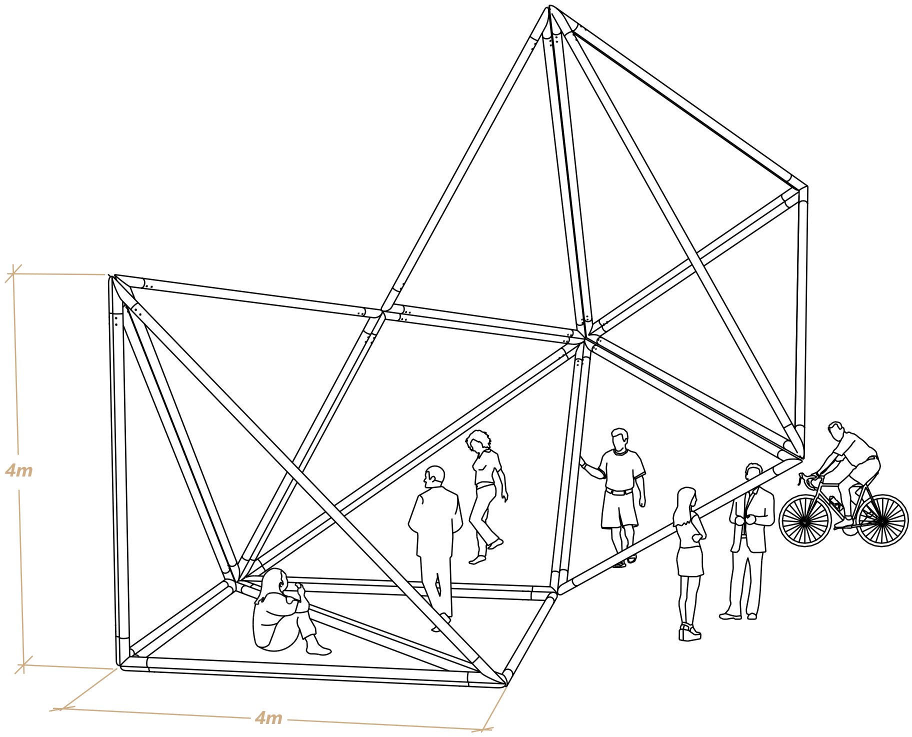
2

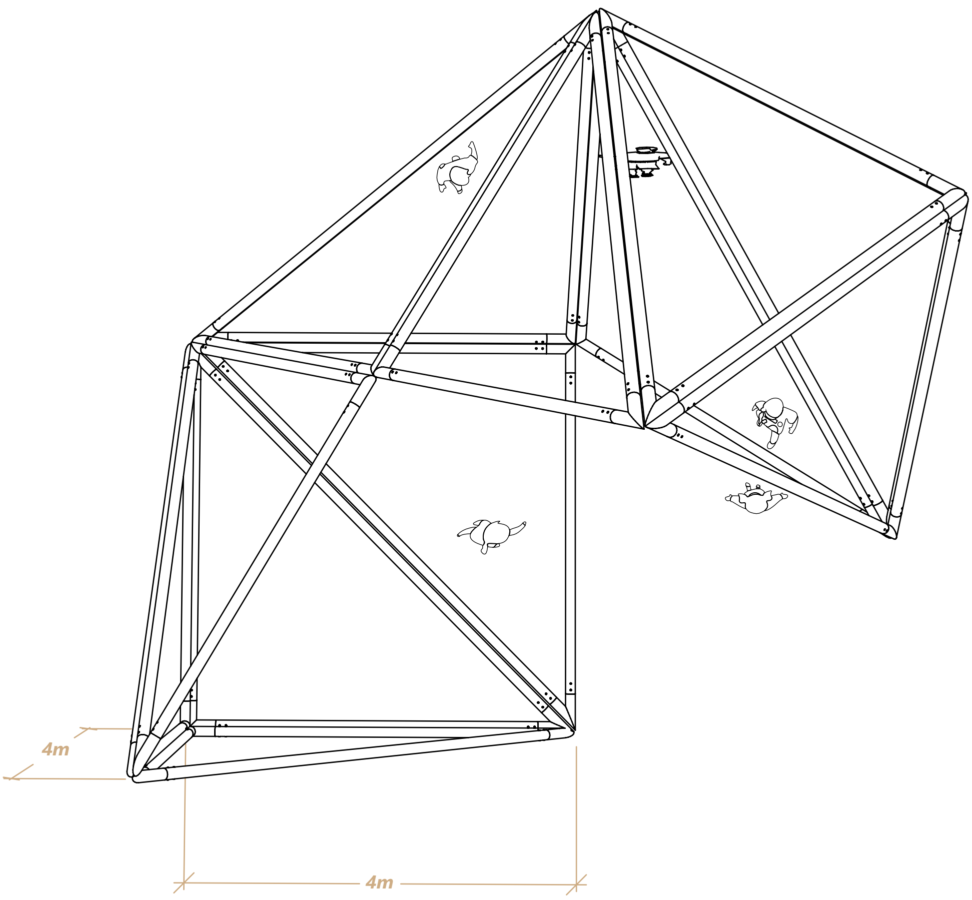
3



photos "***experiment model M1***" © Tetyana Vovk, 2018 "ARCOUSTICON"

drawing M1
"front and top view of pavilion structure"





CONCLUSION

visual aspects of space differentiation

On photo series *(page 39)* we can see some scenario of movement. Not depending on the position, without filling elements between triangles, is very hard to define volume and space difference between inside and outside. Optical construction is perceived as an accumulation of chaotic lines with a very slight differentiation of space. It is difficult to read depth, front and back plans.

actuators

The structural parts of the pavilion system are 4x4x5,6m. They need powerful electromechanical or hydraulic actuators *(photo M17)* that will provide a needed power for rotation along axis (side of triangles). From the metaphorical side, working with such discipline as music you aspect to see very light and weightless (optical feeling) structure. Such big actuators are not a right choice for this metaphorical connection. Perhaps an option can be "marionette dolls" control approach.
Photo M18

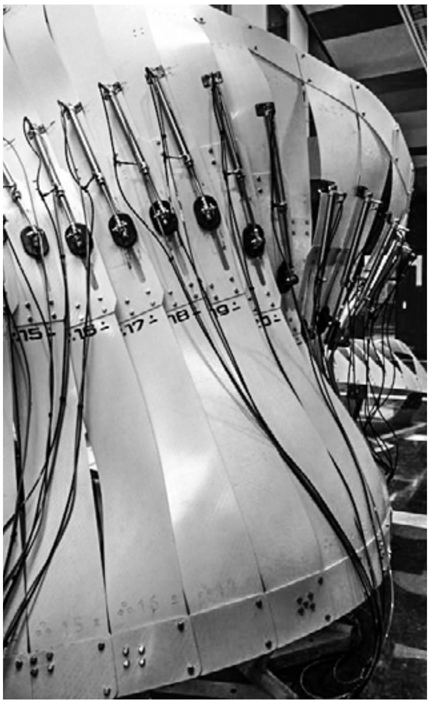


Photo M17, "PARA-Site", Jordi Truco, Elisava 2011. Photo by Arch2O.Com

Example of actuators needed to move structures on a similar scale. PARA-Site is a dynamic and interactive architectural pavilion that is fitted with sensors which react to the presence of visitors, expanding or reducing interior spaces.

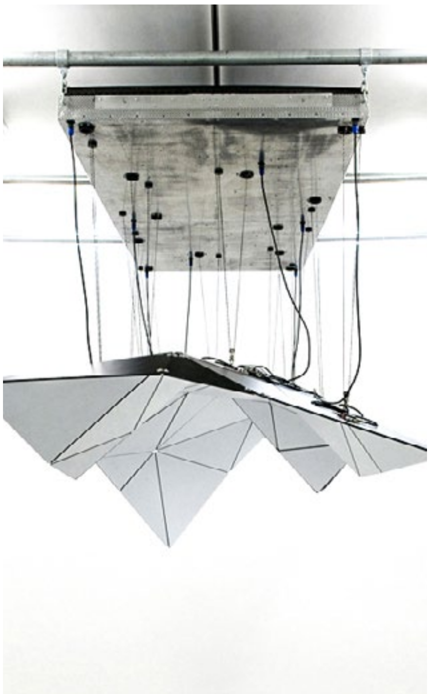
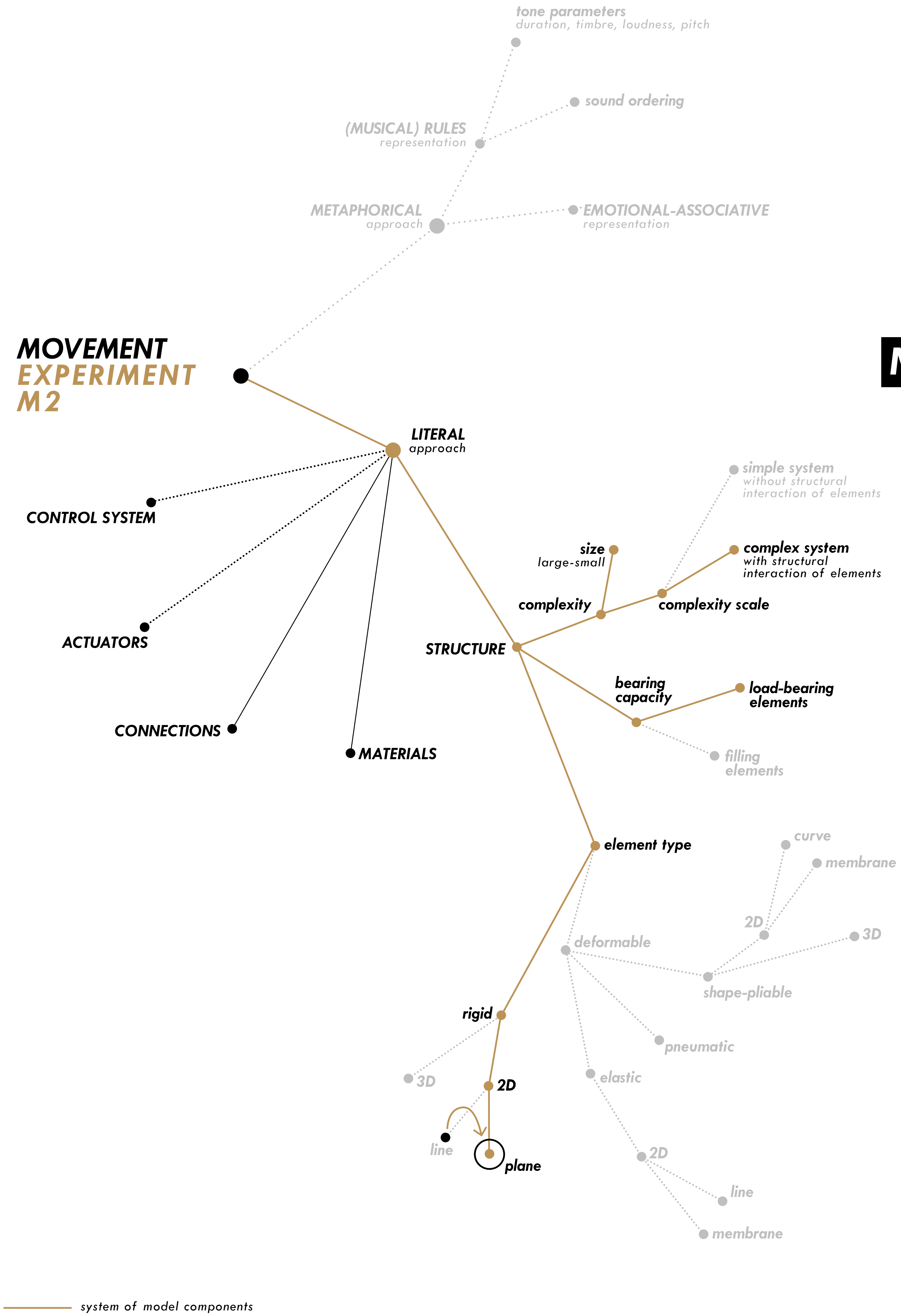


Photo M18, "TESSEL", David Letellier + Lab(au) 2010. Photo by dl@davidletellier.net

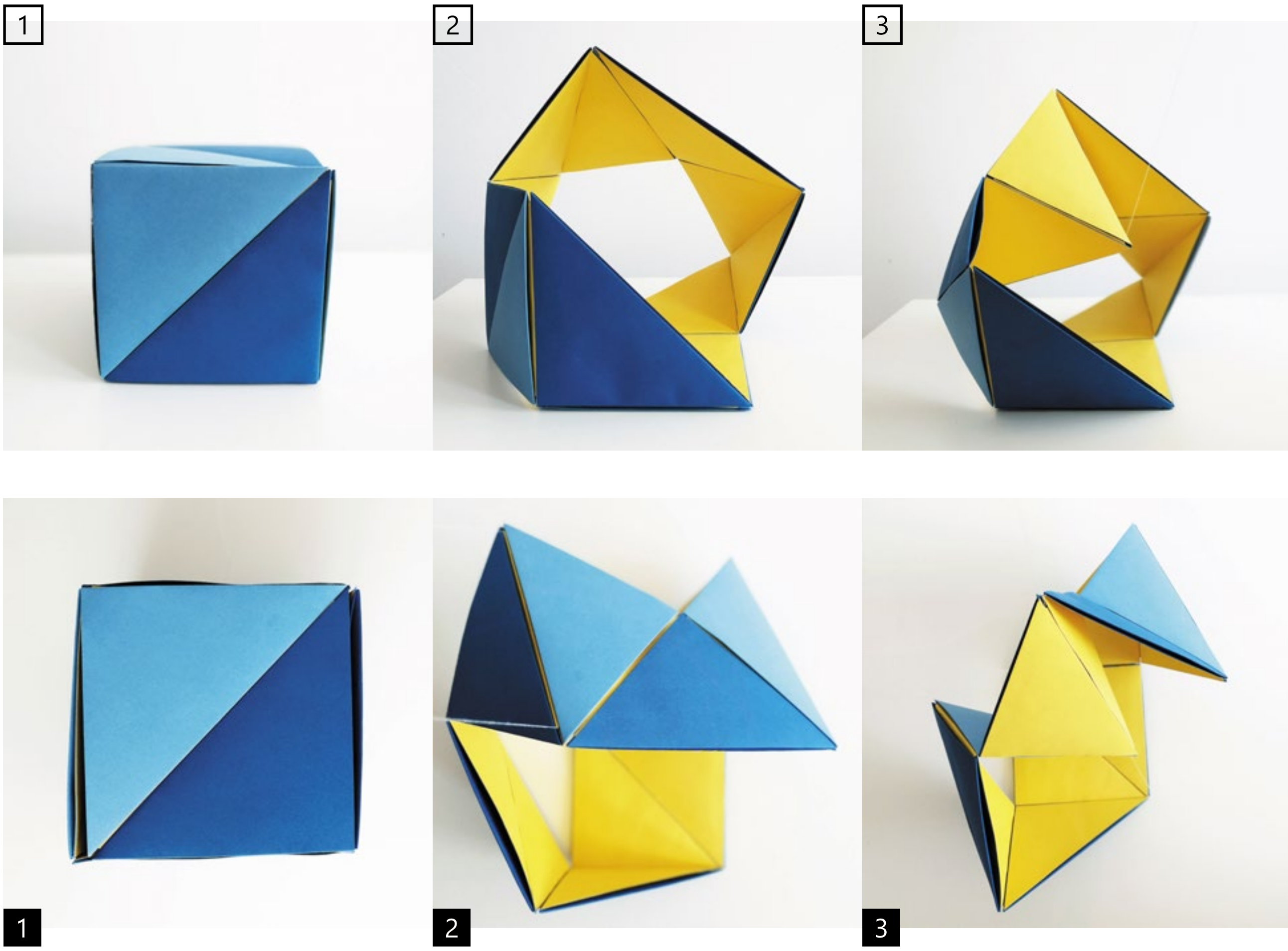
Example of "marionette dolls" approach for control of movement and position in the space. Tessel combines influences that question the link between geometry, movement, and chaos, thus continuing the quest for beauty in the synesthetic perception of sound and spatial phenomenons. "The installation is divided into two parts: an aluminum frame/case which holds all the technical gear and a folding tessellated surface." Letellier, David (2010): TESSEL, https://www.davidletellier.net/TESSEL, last view: 28.10.2018



M2

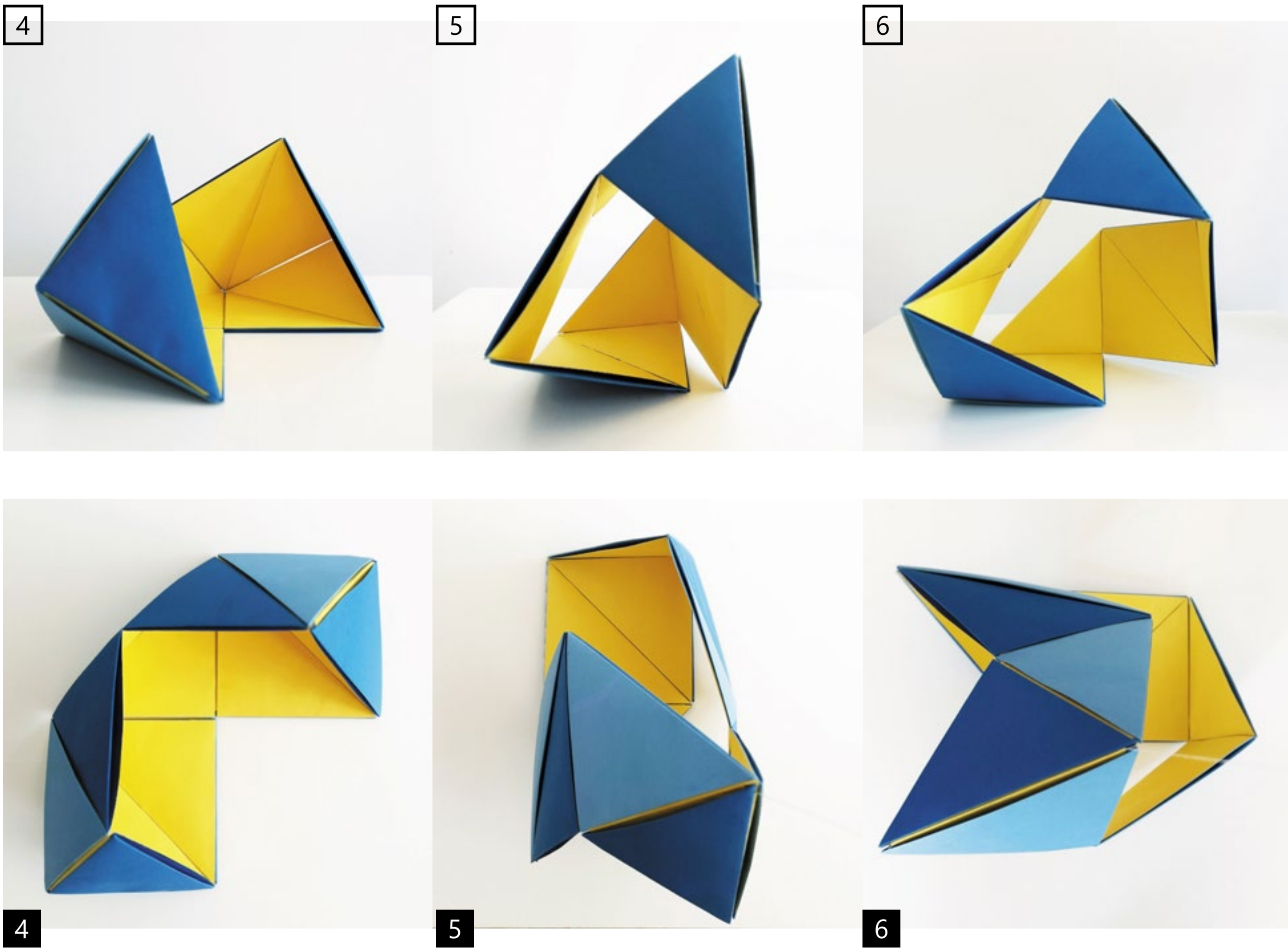
photo on the left side
© Tetyana Vovk, 2018 "ARCOUSTICON"

diagram M13 ***"experiment model M2"***



FRONT VIEW

TOP VIEW



FRONT VIEW

TOP VIEW

*photos "**experiment model 2**" © Tetyana Vovk, 2018 "ARCOUSTICON"*

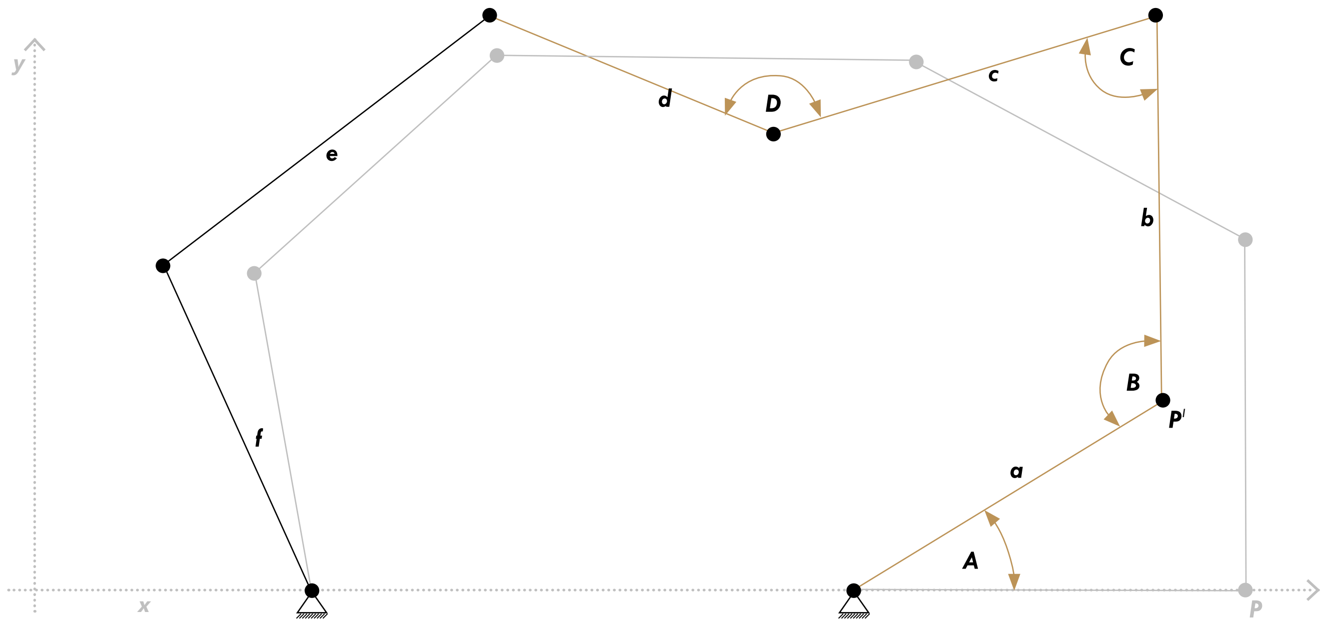


diagram M14 ***"rotated structure"***

CONCLUSION

visual aspects of space differentiation

The conception of spatial transformation considers a process of interaction between the observer's structure of behavior and the structure of the pavilion. When the pavilion is opened the shape changes and invites to interaction. To speak metaphorically, it is as if the pavilion's shape - having felt the music - begins to dance.

control system

The control system is needed to provide an analysis of data, dealing with the spatial position and location of the elements, as well as to send new data with the details of the next provision.

To ensure this process, it is necessary to understand the mechanism of motion of the elements and to describe it mathematically. Generally, all parts are rotating along the axis of connection (hinges) on two of three sides of the triangle. Mathematically this movement is described by the ***rotation matrix***.[1]

1 *"In linear algebra, a rotation matrix is a matrix that is used to perform a rotation in Euclidean space. For example, using the convention below, the matrix rotates points in the xy-plane counterclockwise through an angle θ about the origin of the Cartesian coordinate system. To perform the rotation using a rotation matrix R, the position of each point must be represented by a column vector v, containing the coordinates of the point. A rotated vector is obtained by using the matrix multiplication Rv." "Every rotation in three dimensions is defined by its axis (a vector along this axis is unchanged by the rotation), and its angle — the amount of rotation about that axis (Euler rotation theorem)." Wikipedia (last edited 2018): Rotation matrix, https://en.wikipedia.org/wiki/Rotation_matrix, last view: 28.10.2018*

Let's have a look on a more easy 2-dimensional version of this system, which can be seen in *diagram M14*. To define a new position of points we need incoming data from all degrees of freedom (in this case the angles between lines). Here, data of 4/7 angles are important. This is called the number of the degrees of freedom.

Changing angle ***A***, the whole parts of the system after line ***a*** can be moved till angle ***D***. If all these parts including line ***d*** are fixed, the next lines ***e*** and ***f*** have just one possible position to gain. For this example the rotation matrix will look this way:

$$p'_x = \cos\theta + p^{n-1}_x$$
$$p'_y = \sin\theta + p^{n-1}_y$$

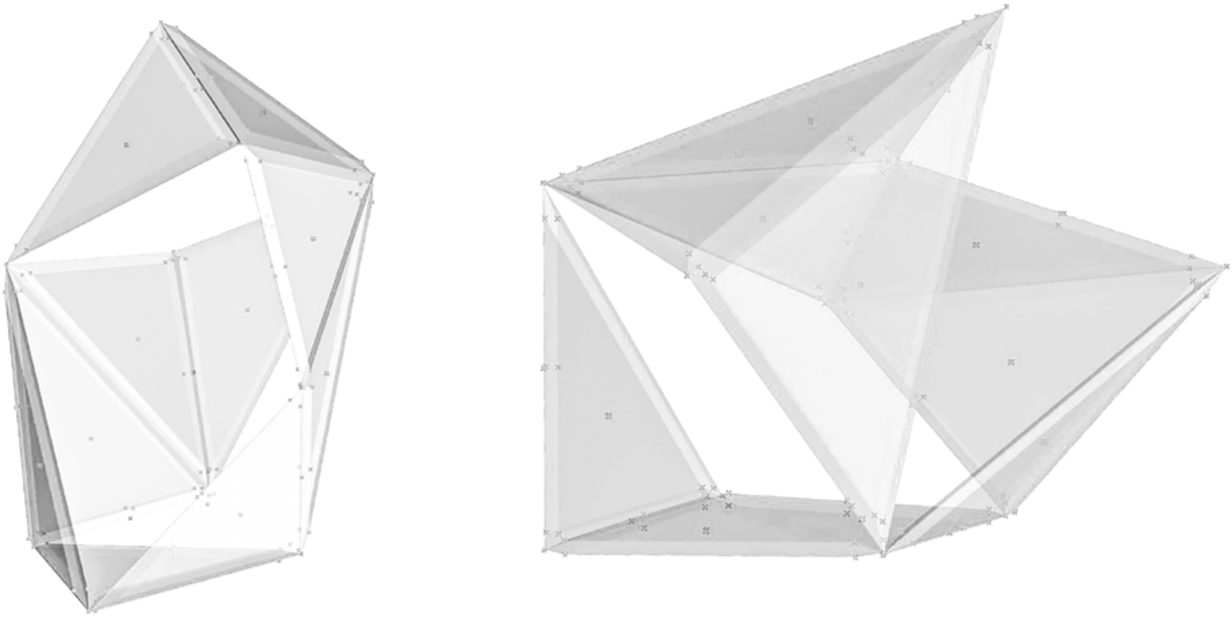


photo series M23, digital simulation of movement

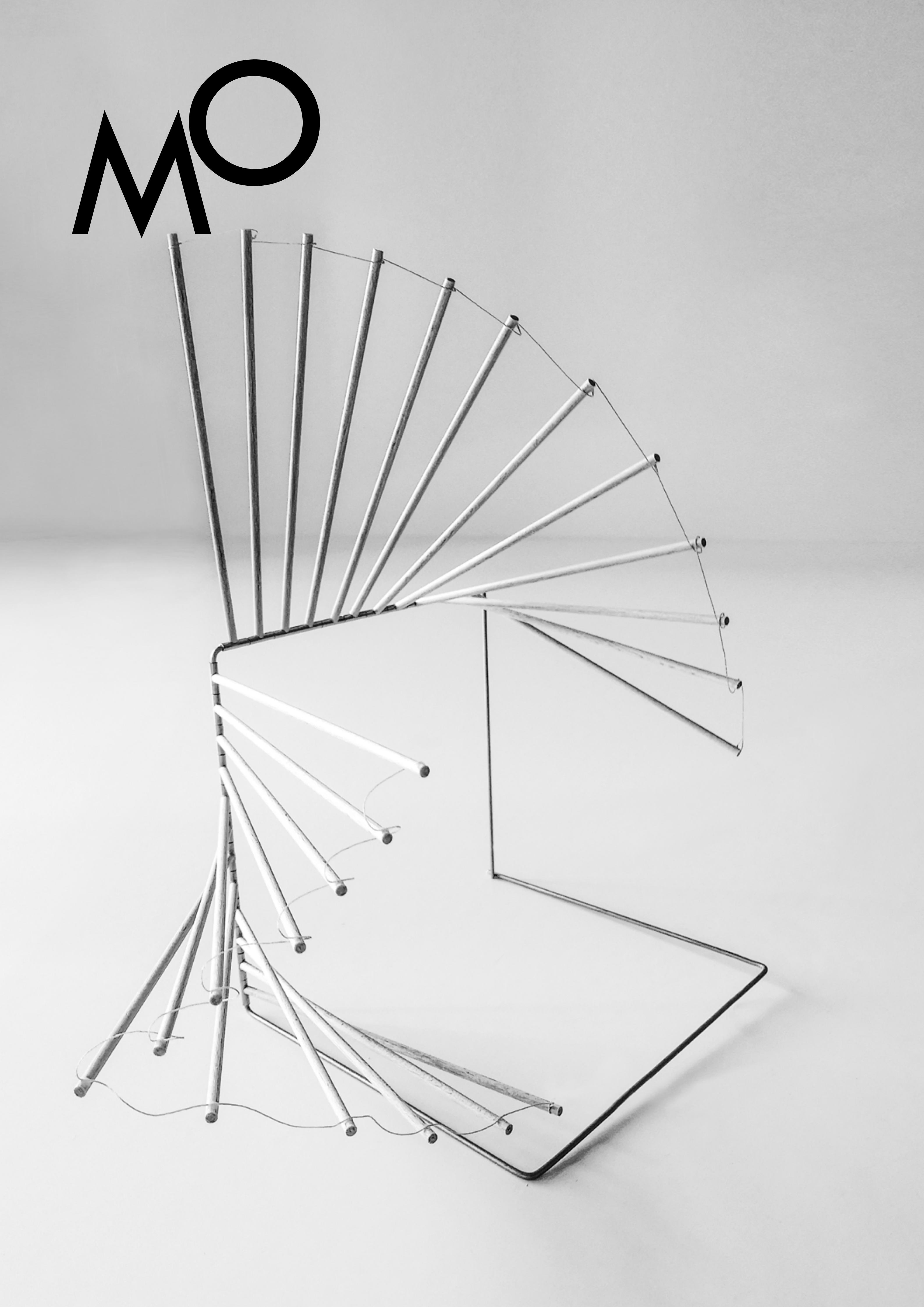
"Rotation matrix for 3-dimensional rotation in the space along axis", Wikipedia (last edited 2018): Rotation matrix, Rotation matrix for 3-dimensional rotation in the space along axis, https://en.wikipedia.org/wiki/Rotation_ matrix, last view: 28.10.2018

$$\begin{bmatrix} \cos\theta + u_x^2\left(1-\cos\theta\right) & u_x u_y\left(1-\cos\theta\right) - u_z\sin\theta & u_x u_z\left(1-\cos\theta\right) + u_y\,\mathrm{si} \\ u_y u_x\left(1-\cos\theta\right) + u_z\sin\theta & \cos\theta + u_y^2\left(1-\cos\theta\right) & u_y u_z\left(1-\cos\theta\right) - u_x\,\mathrm{si} \\ u_z u_x\left(1-\cos\theta\right) - u_y\sin\theta & u_z u_y\left(1-\cos\theta\right) + u_x\sin\theta & \cos\theta + u_z^2\left(1-\cos\theta\right) \end{bmatrix}$$

The same principle works for 3-dimensional rotation in space. In a closed system like a loop, it is more difficult to describe the movement of elements in space, because you do not have a starting angle (all parts are joined together). Controlling the system is very difficult and itself depends on the type of actuators.

Using big elements (4mx4mx5,6m) joined in one complex system will slow down the transformation in space very much and the observer's interaction with the pavilion can not be reflected in shape and change of form.

This is why it makes sense to try other approaches with other scales of movable structure types.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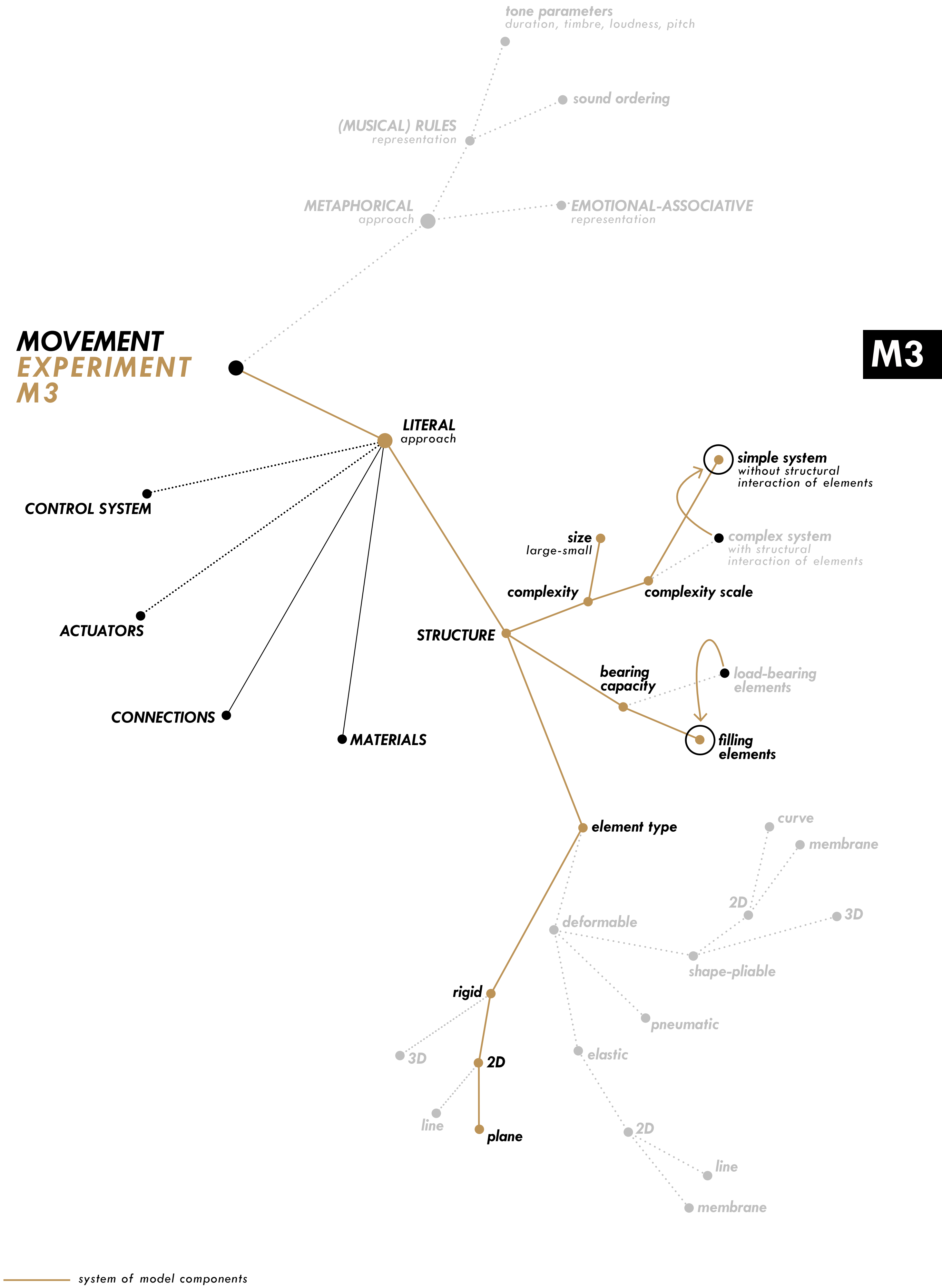
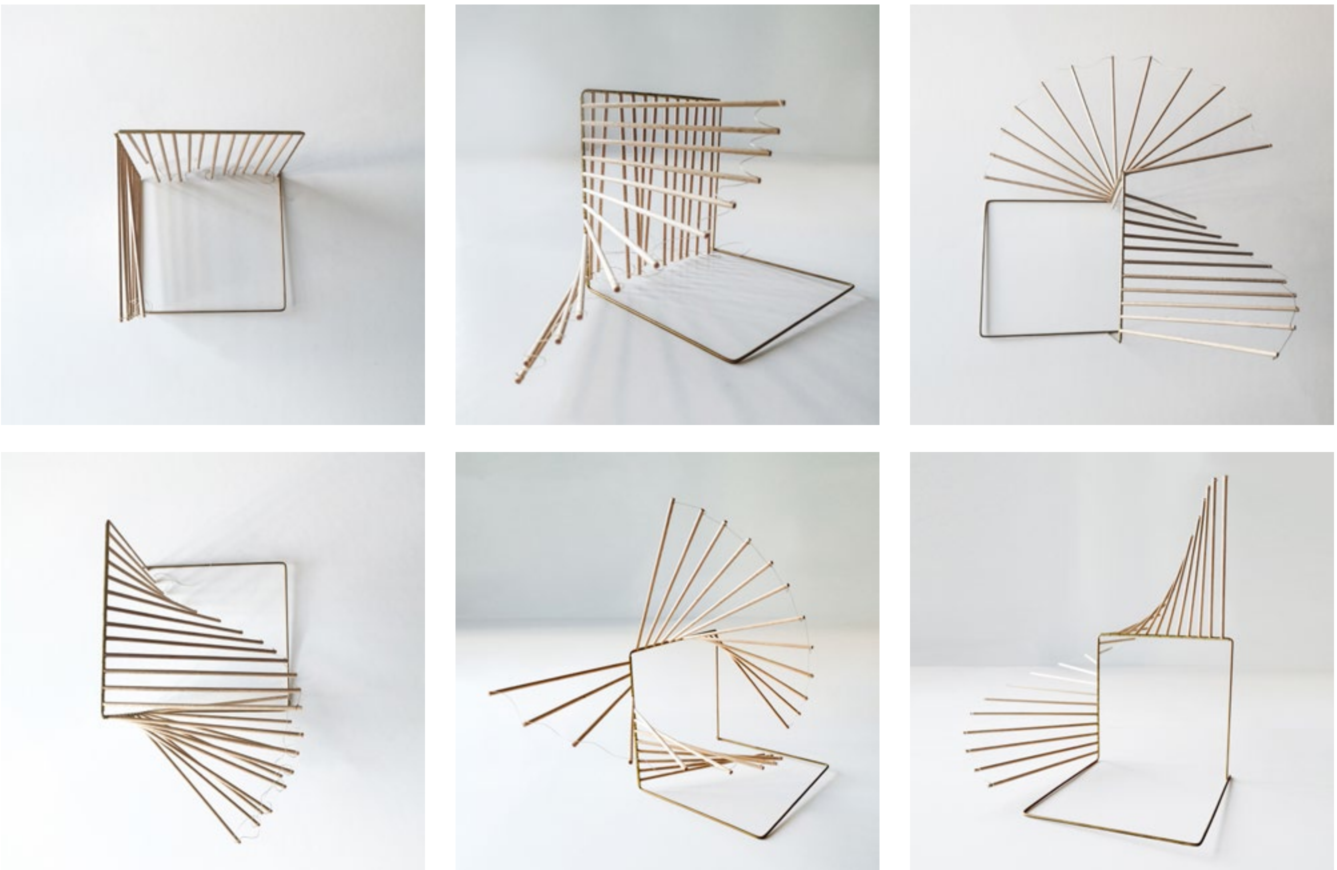


photo on the left side
© Tetyana Vovk, 2018 "ARCOUSTICON"

diagram M15 **"experiment model M3"**



*photos "**experiment model M3**" © Tetyana Vovk, 2018 "ARCOUSTICON"*

MO

DESIGN PROCESS
CONCLUSION
SECTION MOVEMENT

Within the projects prime idea, the musical flow is going to be presented in space creating a musical instrument, through a real-time changeable form.

As we can see in ***experiment M1*** and ***M2***, the complex movable structure systems, despite its small scale, cannot be usable for the ***ARCOUSTICON*** structure.

This type of structures consists of bearing elements joined together into one movable system.

On the one hand, b#y using large and simple elements of structures, to get a more open and "light" space, you need very large and powerful actuators. Without them, it is not possible to provide movement.

On the other hand, by using a smaller scale of structure elements (also means the smaller size of actuators) its number will grow, reducing the optical opening and transparency of the space.

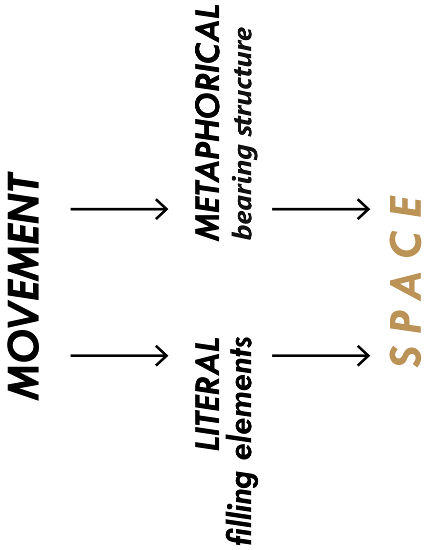
Both types of bearing movable structures are not suitable for forms, that ***need to be optical "light" and "framing"***. So the bearing structure in the future design cannot be movable literally.

The movement of melody and dance has to be expressed metaphorically, as an optical flow and change of form.

But the literal movement can be included in the pavilion by the filling elements, like in ***experiment M3***.

Being just filing elements, those structures don't need to withstand a heavy load.

They also present a more simple system of control. The physical movement of one element does not affect the other. Their main task is to change their position in the space, as a reaction to certain factors.



Together, filling elements are capable to create the effect of a movable form (a visual screen) able to be open or closed, thereby dividing the space. The main two questions, in this case, are relevant for the further design of filling elements:

What kind of materials can be used, so that the moving line does not appear too rough and rigid?

How lightweight can bee the filling elements? (because the size (power) of actuators is linearly dependent on the weight of moving elements. And for design we have to use small and "not visible" actuators).

SPACE

SP

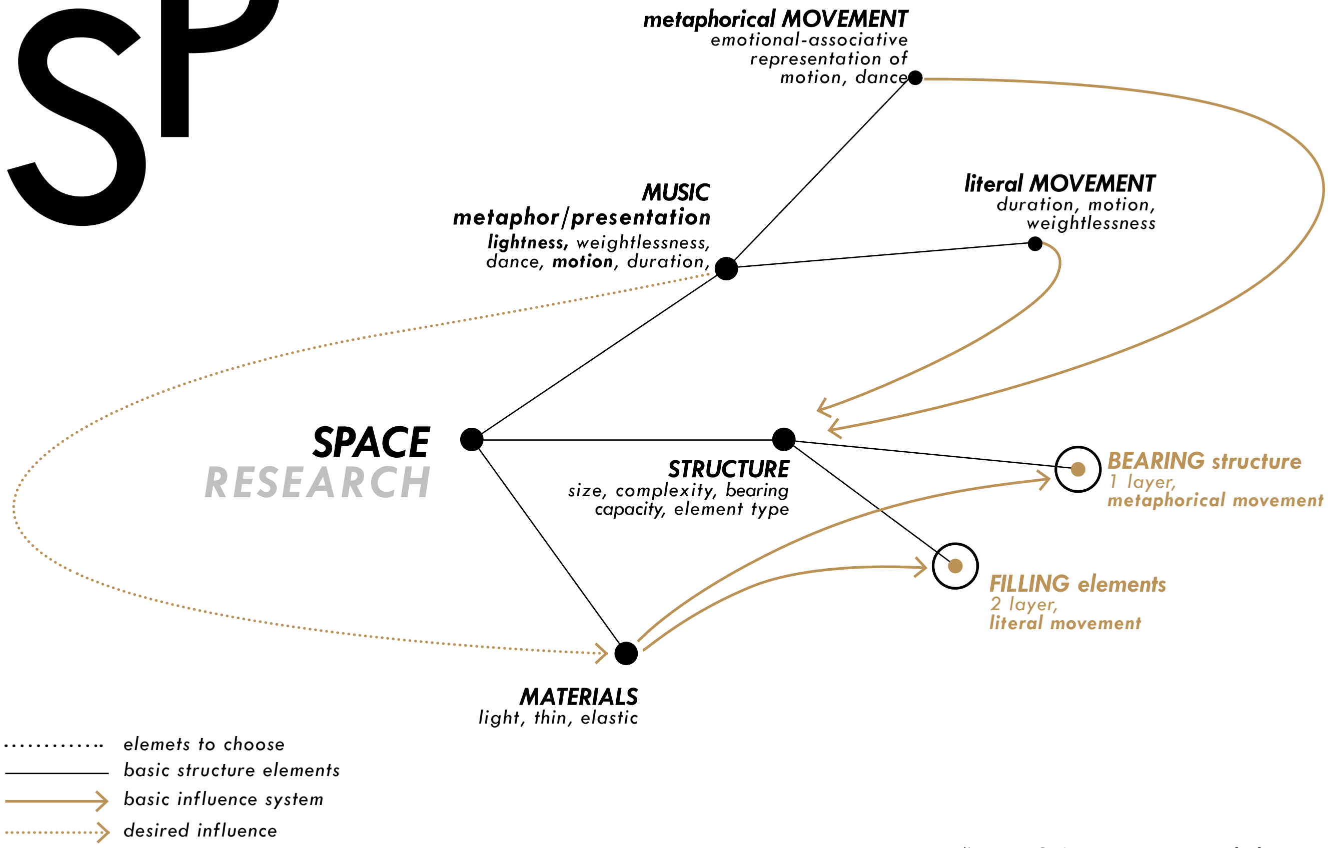


diagram SP1 **"space, structural elements"**

In this section we will talk about ***space as an emotional connection*** with something not easily graspable in architecture: sound and melody.

Proportions, light, and materiality, when coming together, present space, the atmosphere of a building. They illuminate the idea of shape and emotions.

Today architects have much more opportunities to play with those parameters. New technologies and interactive systems, integrated smart materials, light, and virtual spaces allow us to create very special and conceptually oriented places.

The ***interconnection*** between eye and mind happens not only intellectually but also spiritual. That allows to feel something not purely visible but really presenting at the moment.

The range of parameters, that can qualitatively characterize space, is very wide. In this section, I focus only on those that were left after the filtering and screening of alternative development options in the ***"MOVEMENT"*** section.

In this project of an interactive, music and space-creating instrument, ***connection with music metaphorically and literally*** is essential. For the design process, using this approaches (metaphorical and literal), the following parameters stay important: ***lightness, weightlessness, the expression of motion and fluidity through the form.***

These parameters, in turn, affect the choice of the type of structural elements, their dimensional parameters, material and the ability to move in the space.

MOVEMENT
as metaphorical and literal connection between music and space

In the previous ***MOVEMENT*** section, the basic principles and approaches of movement in architectural practice are discussed. Being an expression tool of motion itself it builds a strong metaphorical connection between music and architecture, architecture and behavior *(pages 18-21)*. Generally, there are two possible ways to understand and use motion in space: metaphorical and literally.

In my work, I want to figure out how both of them can be combined in one system to represent and present music through movement in space.

photo SP1 "JS Bach Champer Music Hall", Zaha Hadid, 2009, photo by JOEL CHESTER FILDES

As a conclusion of research in the movement section *(page 52-53)* two ways (layers) of movement implementation in the pavilion structure were stated:

The ***first structural layer*** of the space frame is ***bearing structure***, ss a metaphorical connection between music and space, as a ***representation*** of musical flow and motion, as a dance of form. *(diagram SP1)*

The ***first structural layer*** is the ***load-bearing structure***, seen as a metaphorical connection between music and space, as a ***representation*** of musical flow and motion, as a dance of form. *(diagram SP1).*

SPLINE (CURVE)
as a unifying design idea of both structural layers

If you will try to create a metaphorical or associative form, that can reflect music in its shape, you naturally will come to the problem of balance between something very light and almost barely presenting and in the same time bearing. From this point of view, the shape is more about defining the frames and boundaries of space than about actual room separation.

A wonderful example of this metaphor we can see in the Zaha Hadid project "JS Bach Chamber Music Hall" (Manchester 2009), *photo SP1* The observers' eye is following flexible, elastic curves that create fluid space. The form seems to dance in space, curving and changing its trajectory.

Why do the curvature of the line and its flow of changing orientation cause us to associate it with music and movement? Is it possible, that the imprint of dance and of emotional passion looks like a spline?

Maybe this association is connected with our subconsciousness. Our brain is able to analyze that visual data that we do not always value at a conscious level. Sometimes, only with the help of technology, we can recreate in the real physical world our imaginations and subconscious associations.

photo SP2, "Traces", Lesia Trubat, 2013, photos by L. Jarque, I. Caponio

photo SP3

photo SP4

Examples are the best way to trace these transition and development. From this point of view, the works of Spanish artist Lesia Trubat are very interesting. Beginning with a project *"Traces"* in 2013 the artist tried to record the "memory of a dance" as footprints during a movement.[1]

Using different approaches with salt and ink, she was able to create 2D prints, like probably all of us tried to do on the sand as children. *Photo SP2, SP3, SP4*

Project *"Electronic Traces"* is the next step of evolution. An attempt to move from a two-dimensional to a three-dimensional space.

"Using new technology, developed in collaboration with Lilypad Arduino, Lesia Trubat was able to turn a pair of ballet shoes into a digital paintbrush by fitting them with a device that allows her to track the dancer's every plié, point and arabesque. The device, which is fitted directly to the shoes, then translates the ballerina's movements into a beautiful series of abstract digital images, using a specially-designed smartphone app".[2]

1 *Trubat, Lesia (2013): Final Degree Project ELISAVA, Traces, Electronic Traces*

2 *Lankston, Charlie (2015): Innovative new pointe shoes turn a ballerina's movements into unique works of art by digitally tracking her dancing, MailOnline, https://www.dailymail.co.uk/femail/article-2822099/Innovative-new-pointe-shoes-turn-ballerina-s-movements-unique-works-art-digitally-tracking-dancing.html, last view: 28.10.2018*

photo SP5, "Electronic Traces", L.Trubat, 2013, photos by by L. Jarque, I. Caponio

photo SP6, "Electronic Traces", L.Trubat, 2013

photo SP7, ***the virtual presentation of the dance***
"Electronic Traces", L.Trubat, 2013

photo SP8, ***reflection (representation) of the dance through spline in the physical world***
"ALICE" Kimihiko Okada, 2006, photo by Kimihiko Okada

LAYER 1 *bearing structure - METAPHORICAL MOVEMENT*

BENDING ACTIVE STRUCTURES as a form-finding method

SP

1. LAYER
BEARING STRUCTURE
BENDING-ACTIVE STRUCTURE

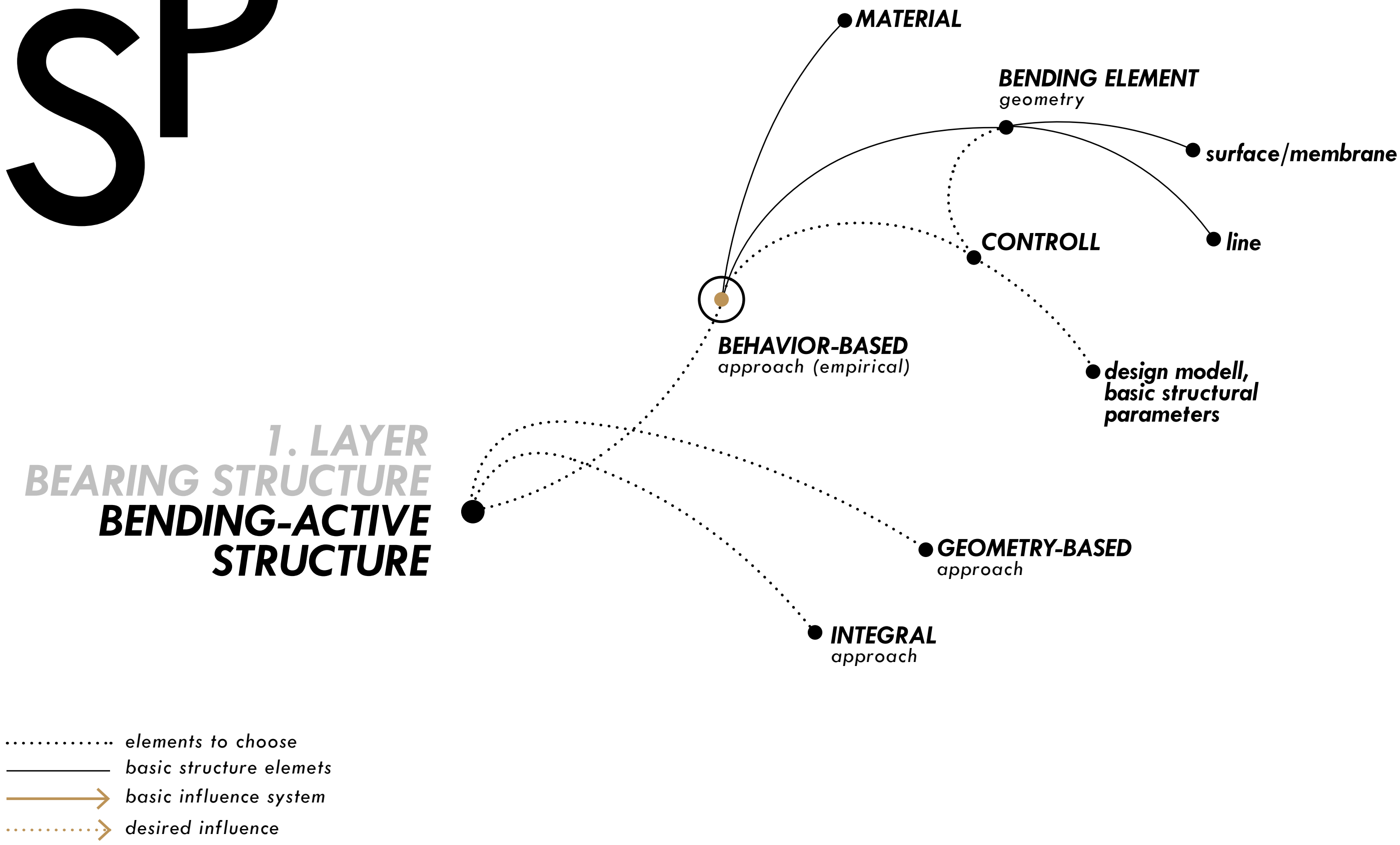


diagram SP2

The purpose of this chapter is to optimize the form of ***ARCOUSTICON'S*** bearing structure. Based on the aesthetic and metaphorical connections described above, the ***spline*** serves as the starting structural unit in design.

When we talk about spline structures, we usually understand: ***rigid* "frozen"** elements produced in the form of a curve, or ***rigid*** elements with their ability to ***elastic deformation*** through some bending stress or ***deformable elastic*** elements, which are changing their shapes under their own weight and gravity.

Keeping in mind that level 1 is the level of the pavilion's bearing structure, we consider only two first types of elements, that are, the bending-active structures and "frozen" structures.

BENDING-ACTIVE STRUCTURES

"are structural systems that include curved beam or shell elements which base their geometry on the elastic deformation from an initially straight or planar configuration"

Julian Lienhard, 2014, "Bending-Active Structures"

The design approach of bending active structures develops together with technologies. Today there are three different approaches to define: behavior-based, geometry-based and integral *(diagram SP2)*. But only two are actually used: behavior-based and integral. The *diagram SP3* shows the main difference between them.

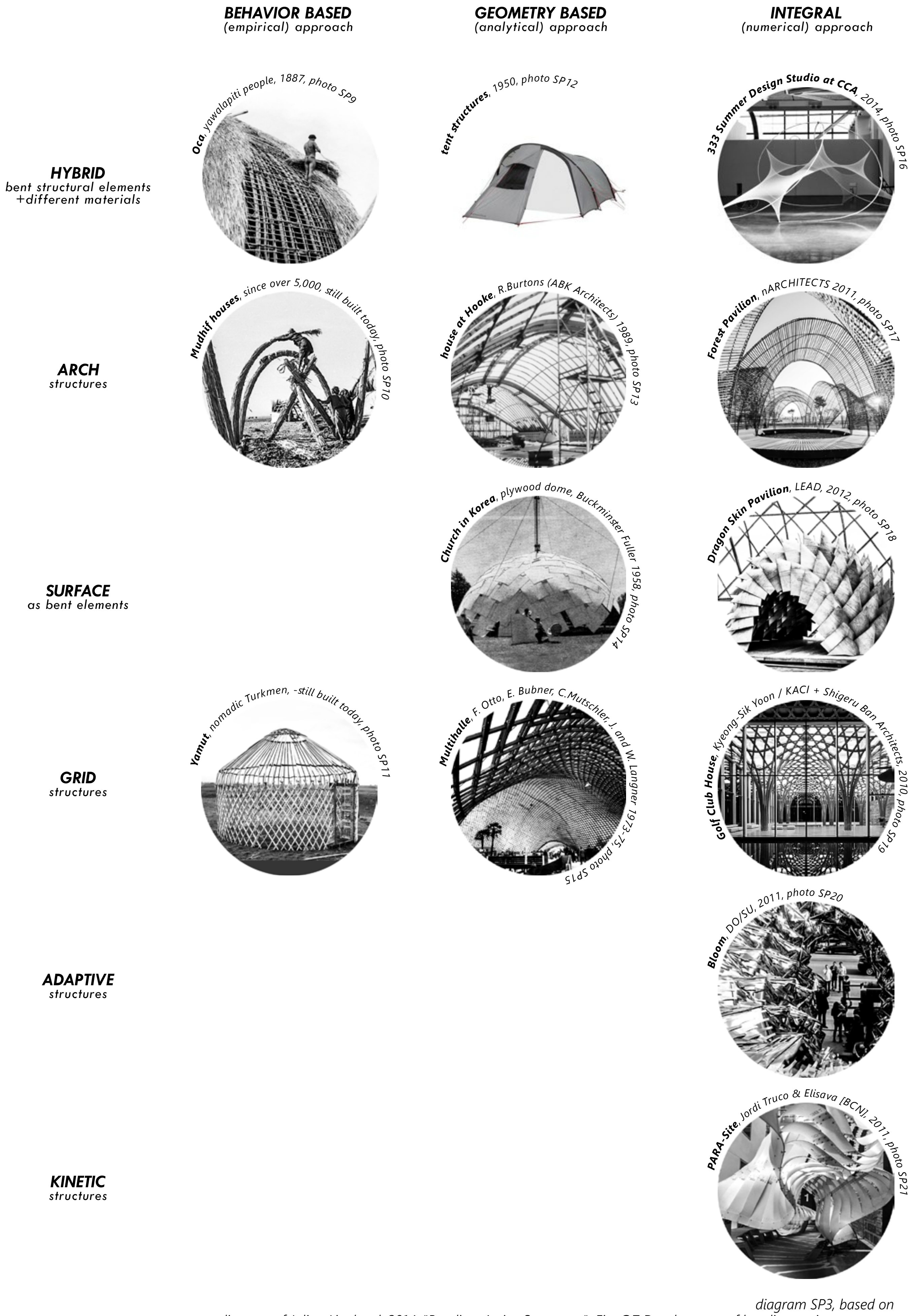


diagram SP3, based on
diagram of Julian Lienhard, 2014, "Bending-Active Structures", Fig. C.7 Development of bending-active structures

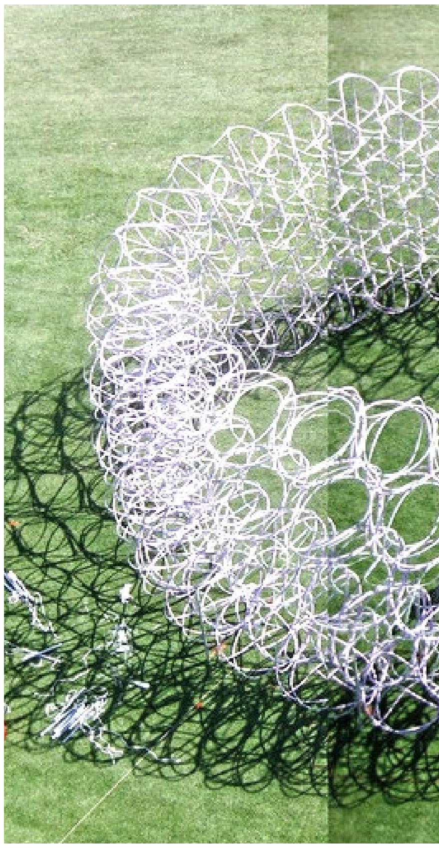


photo SP22, "Eco-resort Pavilion", Vo Trong Nghia, 2008, photo by Nguyen Quang Phuc

BEHAVIOR BASED APPROACH

This approach provides ***empirical tests of material limitations***, depending on geometrical and structural system capabilities.

It is the oldest approach and is known from vernacular architecture since 5000 BC. (Mostly as tension arc systems of bamboo structures, temporary or mobile shelters)

By 1950 most of the structures designed according to this approach had a relatively similar and analogical geometrical form of the structures. However, after technological development in 1950, it is increasingly changing and is becoming more varied.

On the one hand, new methods of data analysis and calculation of elastic and static design capabilities are a significant push that provides forms variability.

On the other hand, it is a search for an invention of new materials as a high breaking strain that includes considerable self- equilibrating bending stress. The materials reache from wood to iron and to steel and finally to polymers.

This significant step allows us to achieve stability and bearing capacity of structures where it was not previously possible.

All this makes the behavior-based approach actual today and usable the in design and research of forms. Usually used in small-sized structures this method stays relevant today, providing a strong tactile connection between designer and material, form and stress level (*photo SP24).*

photo SP23, "Elastic Plastic Sponge", GOLDSPACE, 2009, photos by hegoldspace.com

photo SP24, "Elastic Plastic Sponge"

GEOMETRY BASED APPROACH

This approach has been used in the middle of the 20th century as attempt to find an economic way for constructing larger weight and double curved shell structures, double curved surfaces and gridshells.[1]

It has not been used at the time of computational simulation possibilities to calculate and simulate large elastic structures deformation. But for geometry symmetrical structures it was good enough and allowed architects to cover fairly large areas and pavilions.

For more complex projects the most common was a "hanging" form finding method. Flat grids were suspended at certain points, so the geometry of natural bending form was found empirically.[2] *(diagram SP3).*

1 Lienhard, Julian (2014): Bending-Active Structures, Stuttgart: Active Bending in Building Structures, pp. 52-55

2 for example project Multihalle by F. Otto, E. Bubner, C. Mutschler, J. and W. Langner, 1973-1975

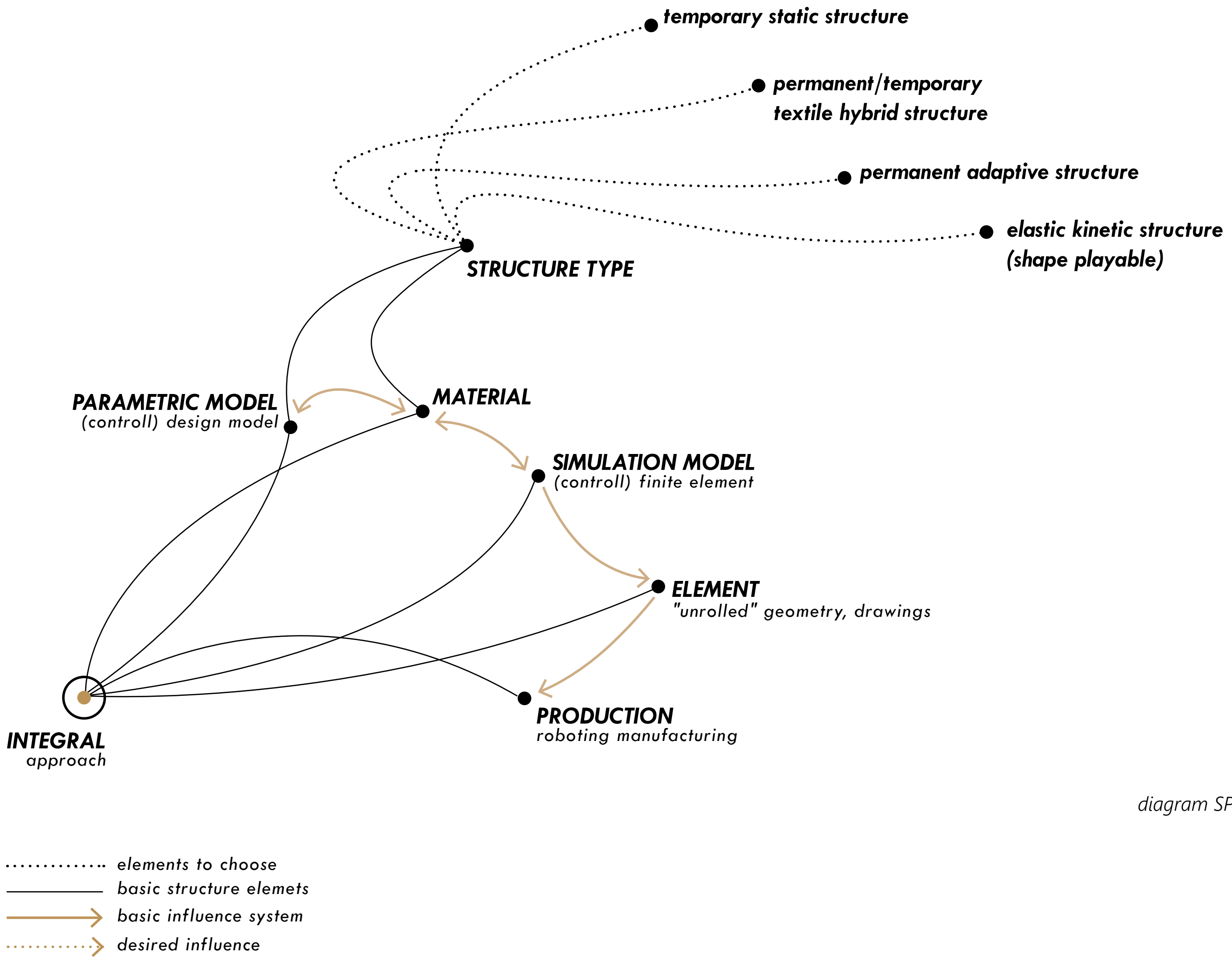


diagram SP4

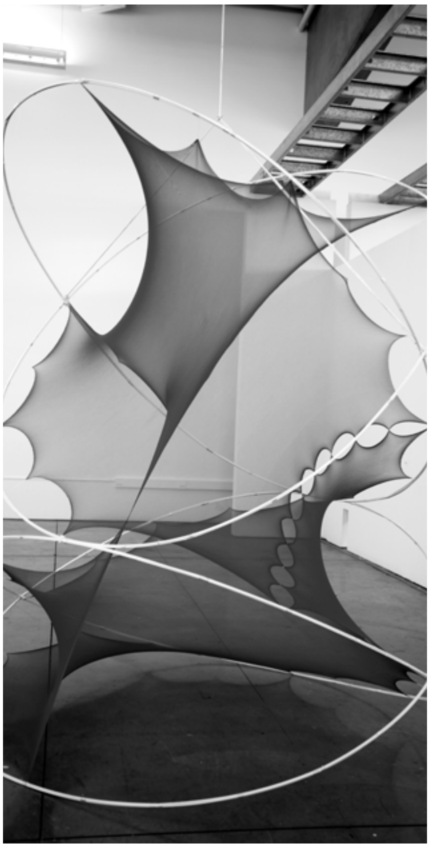
INTEGRAL APPROACH

The Integral approach is a numerical form finding method of elastic deformation of the structure. It allows full control of the characteristics of the material and its limitation (parameters are included in the numerical analysis model).

Generally, this approach is used for designing complex geometries and non linear deformation. It allows the use and control not only of one type of structure element, but a of combination as a complex bent "hybrid" system. Elastic beams, form-active surfaces, pre-stressed membranes working together produce much higher stiffness by smaller cross-sections as the only bent element itself.

That is why the integral approach works best in the condition of a difficult and complex system. Depending on the type of used material and the type of elements, these are the following types of bending-active structures to determine: ***temporary static, permanent/temporary textile hybrid, permanent adaptive structure, elastic kinetic (shape playable)*** *diagram SP4.*

The following photos show some of these systems in praxis.



temporary static structure
photo SP25, "Dragon Skin Pavilion", G. Retsin, EDGE Laboratory, 2012, photo by P. Tynkkynen, E. Keskisarja

temporary textile hybrid structure
photo SP27, "333 Summer Design Studio at CCA", 2014, photo by soto-architects.com

permanent elastic kinetic thermobimetal surface structure
photo SP29, "Bloom", DO/SU, 2011, photo3 by dosu-arch.com/bloom

photo SP26

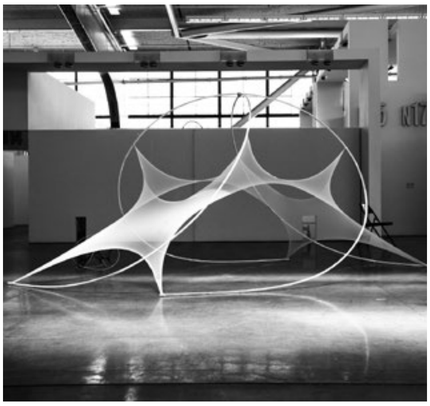
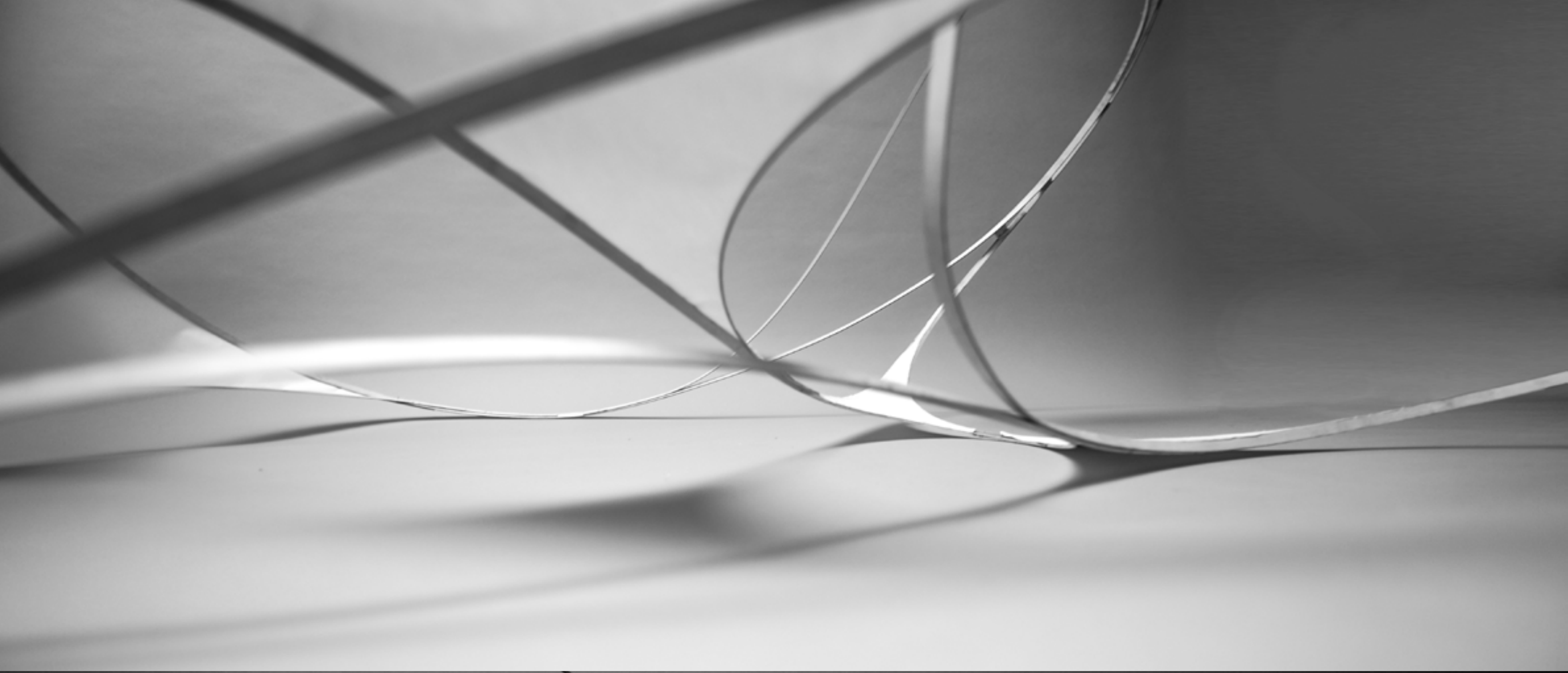
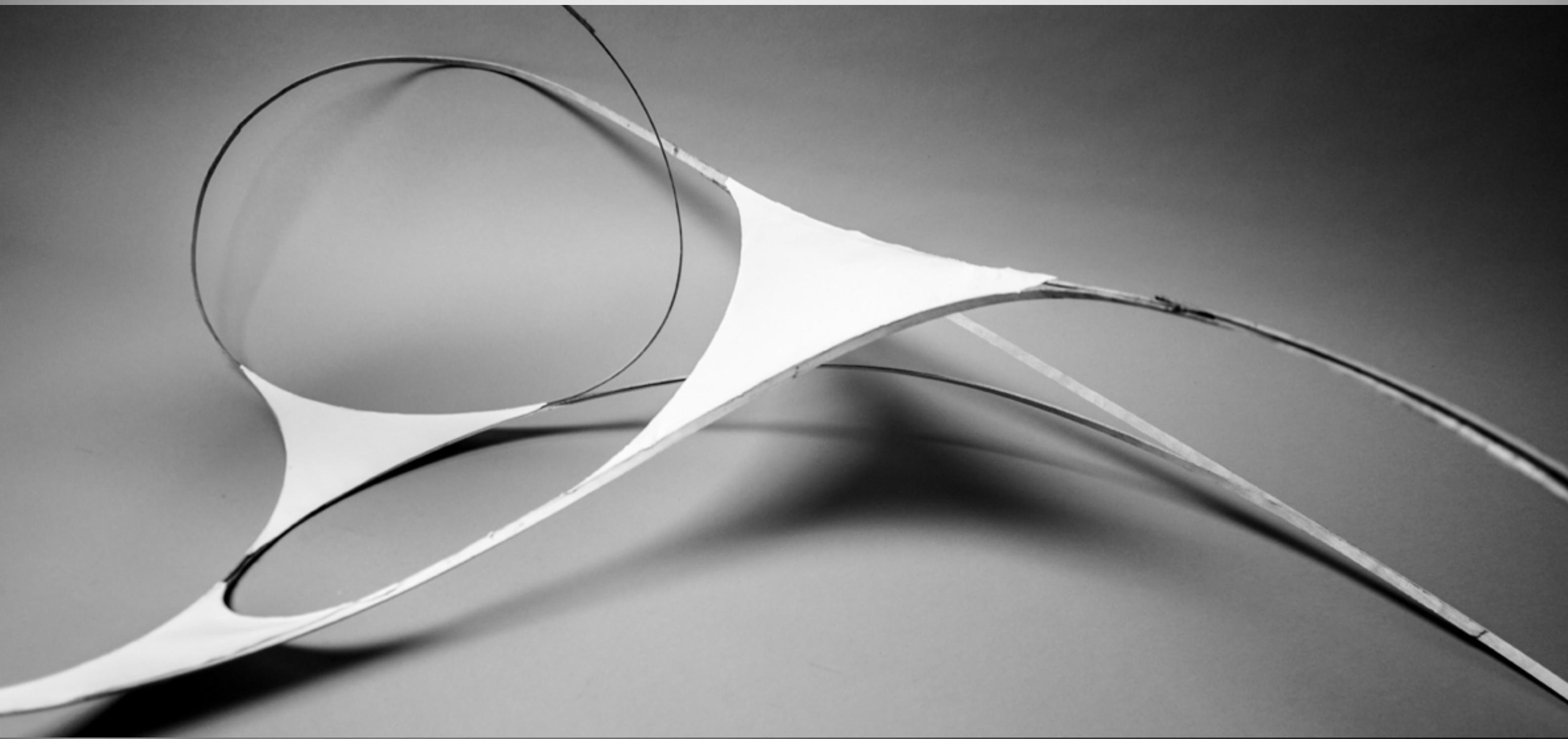
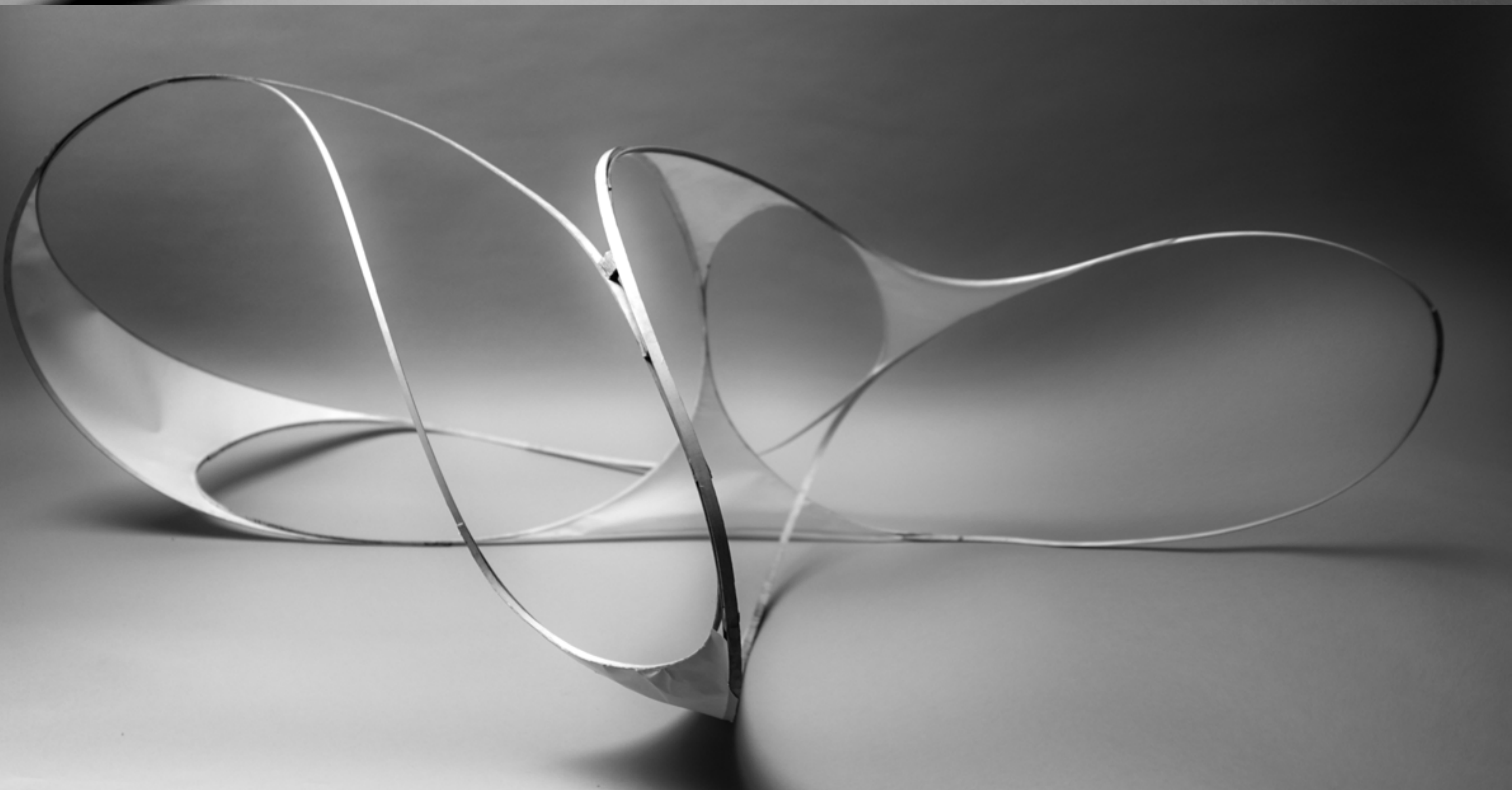


photo SP28

photo SP30

SP

SPACE

1. LAYER

BEARING BENDING-ACTIVE STRUCTURE

EXPERIMENT SP1

SP1

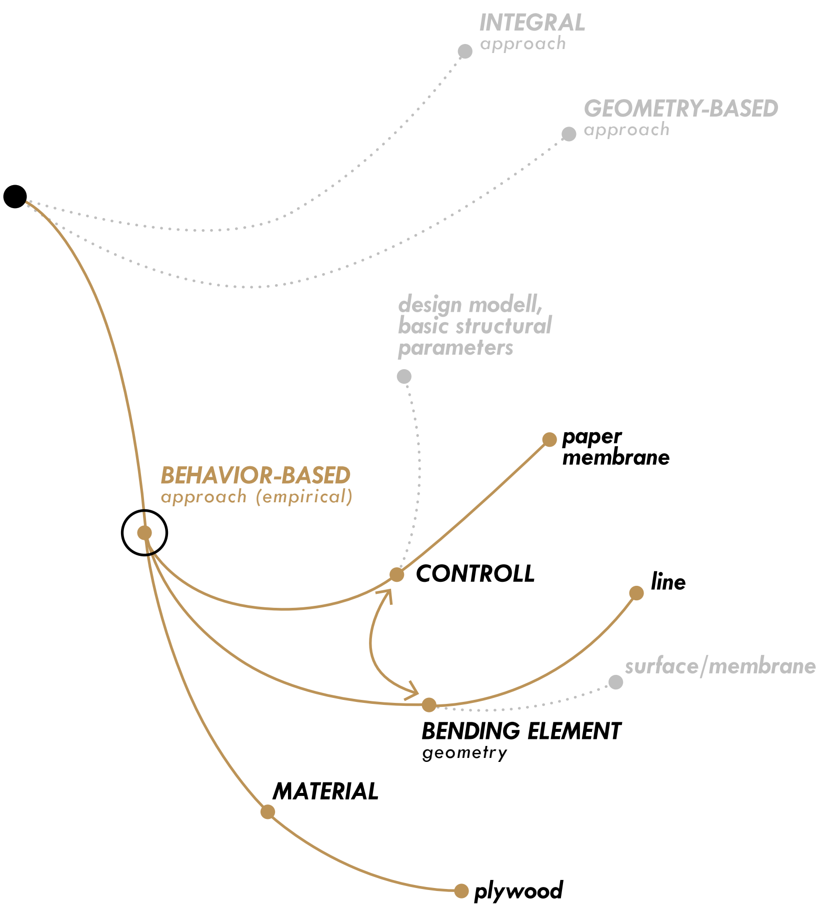
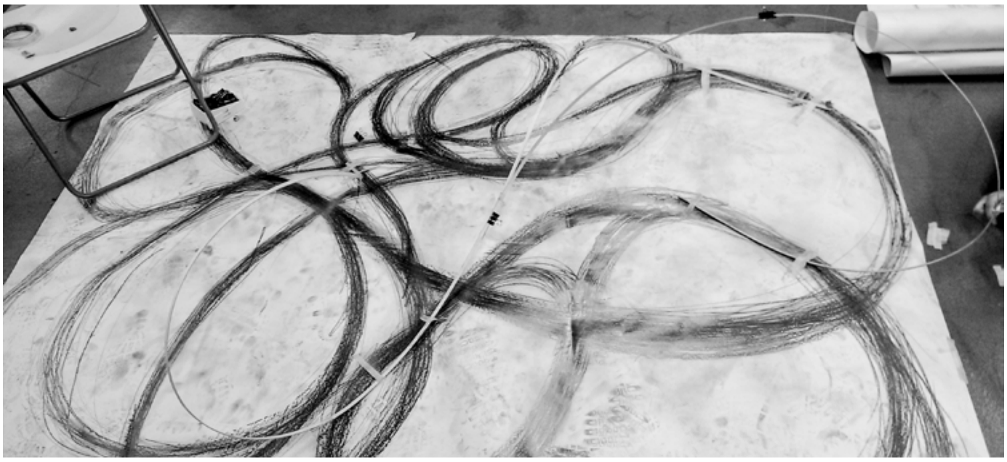


diagram SP5 "**experiment SP1**"

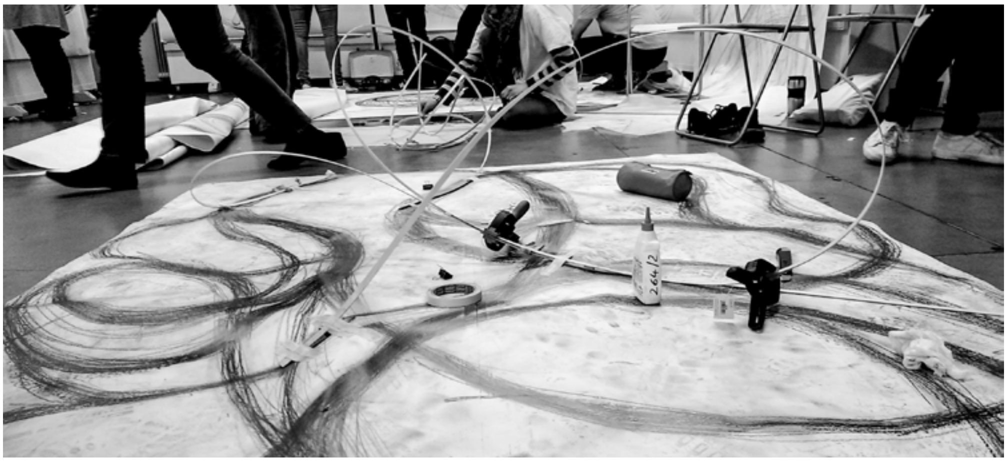
This experiment is an attempt to apply the line as the main constructive element of the form. The form finding process itself is aimed at finding the optimal structure as a transition between a two-dimensional representation of motion into a three-dimensional *(the photos on following page).*

In this experiment, I interpret line through a strip of plywood with a section 2x3mm (bending active material).

photos on the left side



1



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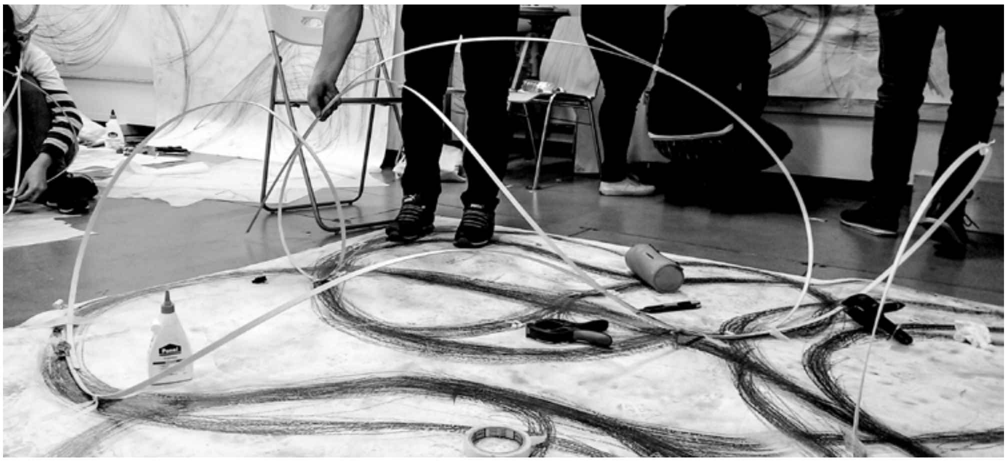

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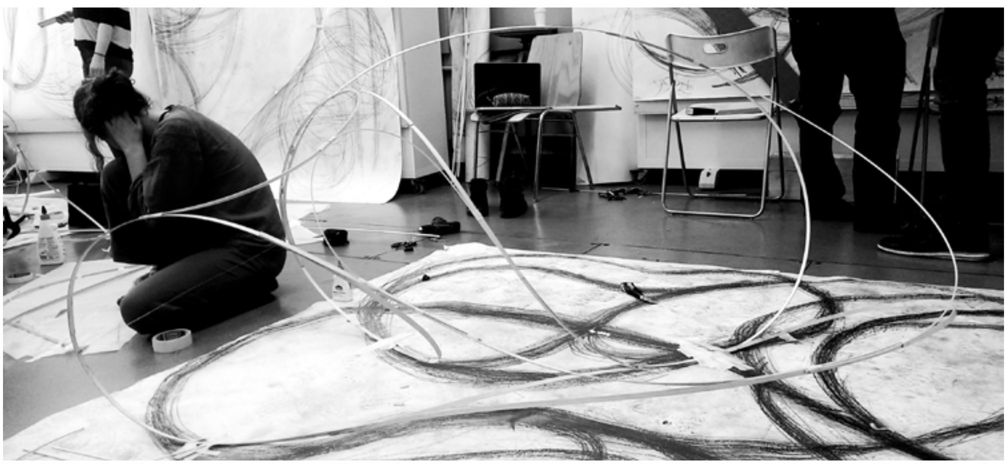

4

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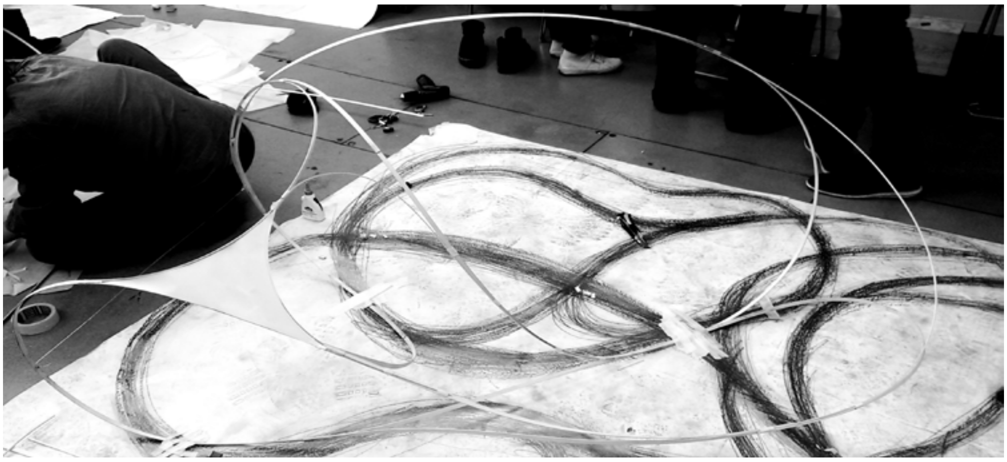
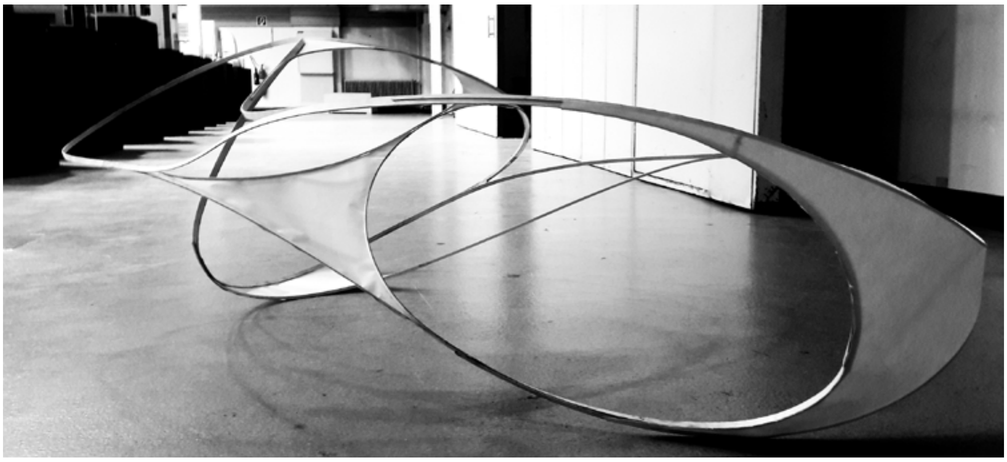
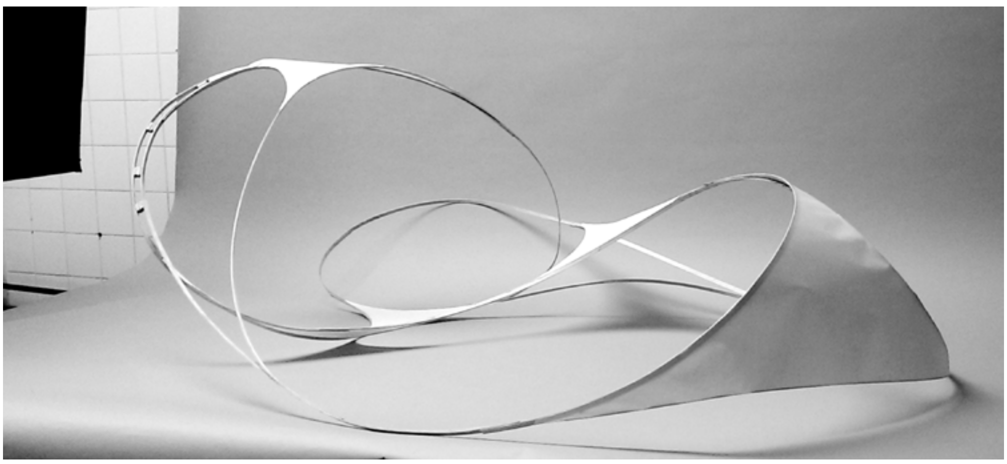


6

7



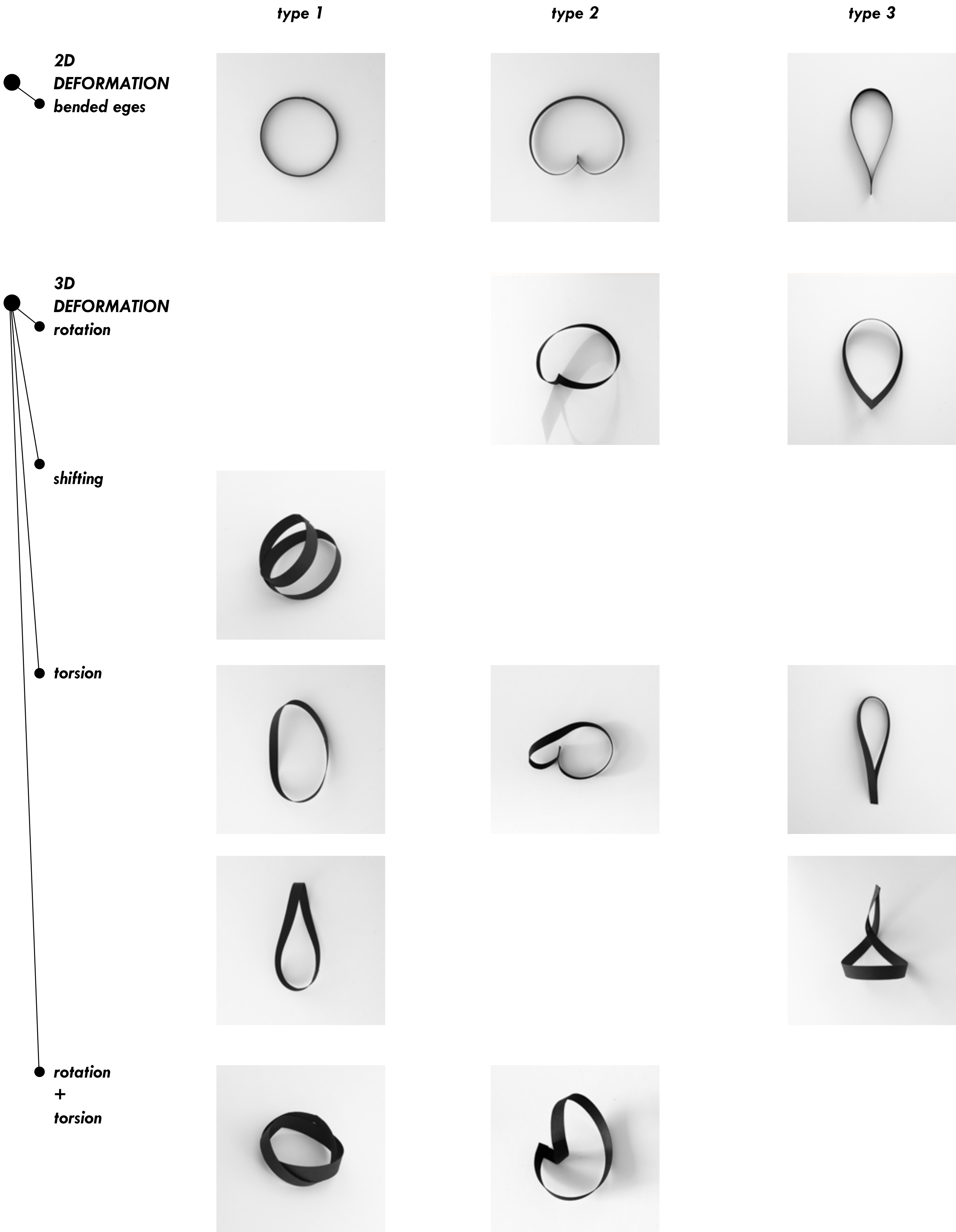
8



photos © Tetyana Vovk, 2018 "ARCOUSTICON"

DEFORMATION TOPOLOGY

diagram SP6



type 4

CONCLUSION

After an empirical research to get acquainted with bending-active structures, the following parameters are defined as important: implementation of approaches that generate 3D deformation and control of this deformation.

3D DEFORMATION

The topological research of simple structure deformation in this experiment is represented on the *diagram SP6*.

To provide transformation of the form from the planar level to the three dimensional one, it is necessary to use one of the following elements for transformations: rotation, torsion, shifting or their combination. This helps to provide the necessary stress of structure elements for the elasticity of the system and superior bearing capacity.

An interesting observation is that the third element type *(diagram SP6)* becomes the basic one and is often found in the final form-structure. Despite the fact that at the beginning this type of form did not exist, it was formed in the process of finding the optimal version for the construction stabilization, by combining different lines between each other *(photos of the design process on previous pages)*.

CONTROL

The second important point is the control of the system. On a series of photos, documenting the design process, it can be traced how each additional level of linear bonds limits the undesirable deformation of the form and gives it rigidity.

At the same time, an important role plays the filling membranes or surfaces *(in this experiment made from paper, photos 5,6,7,8)*. They provide the basic stiffness of the structure by bending her edges with each other. Without those elements, the distance between sides would be constantly changed, thereby generating new forms, what is not desirable.

According to the initial design idea, the filling elements have to be movable elements. Therefore, for future experiments with a form, stable elastic membranes will need to be replaced by another connector, such as elastic linear connections (laces) between active-bended splines. That will provide the necessary stability and control as well as an opportunity to implement the filling elements as movable elements in other places.

SP

SPACE
1. LAYER

BEARING BENDING-ACTIVE STRUCTURE

EXPERIMENT SP2

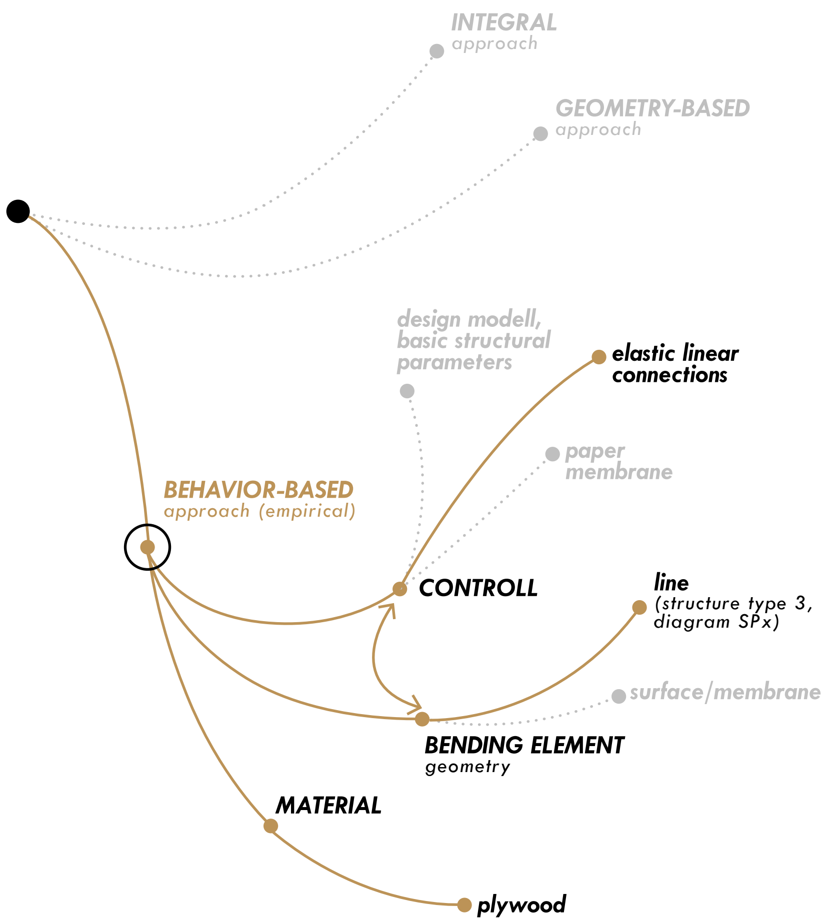


diagram SP7 "**experiment SP2**"

In this ***experimental model SP2***, its form deformation (form finding) happens by connection of bending-active elements (wooden strips) between each other and the stretched linear(strings) connections between some sides of this structure. Linear connections took over the same control function in this form, as paper membranes in the first ***experimental model SP1***.

The photos of steps 2 and 3 show how the shape begins to revive, shifting from a two-dimensional plane to three-dimensional space.

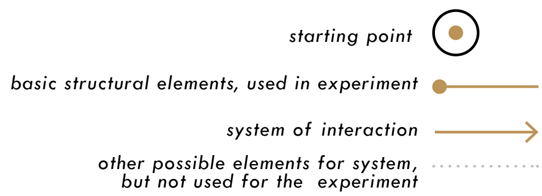
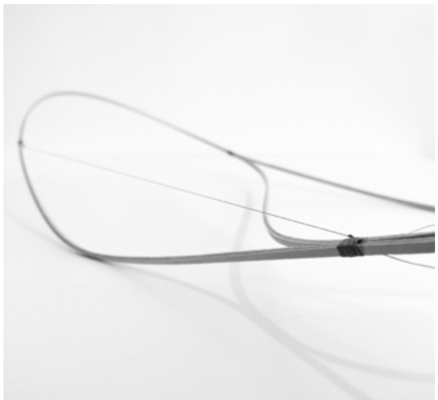
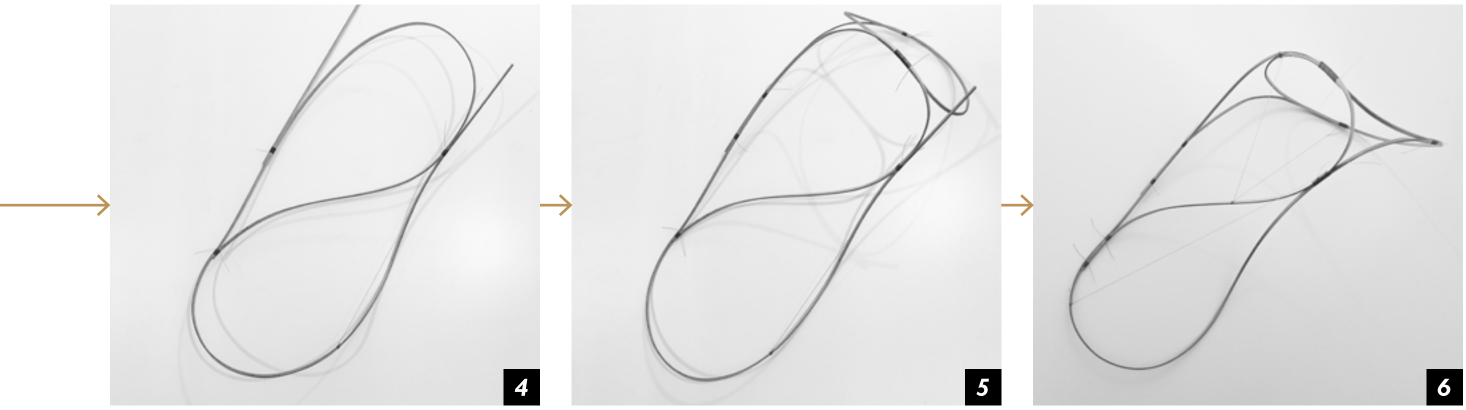


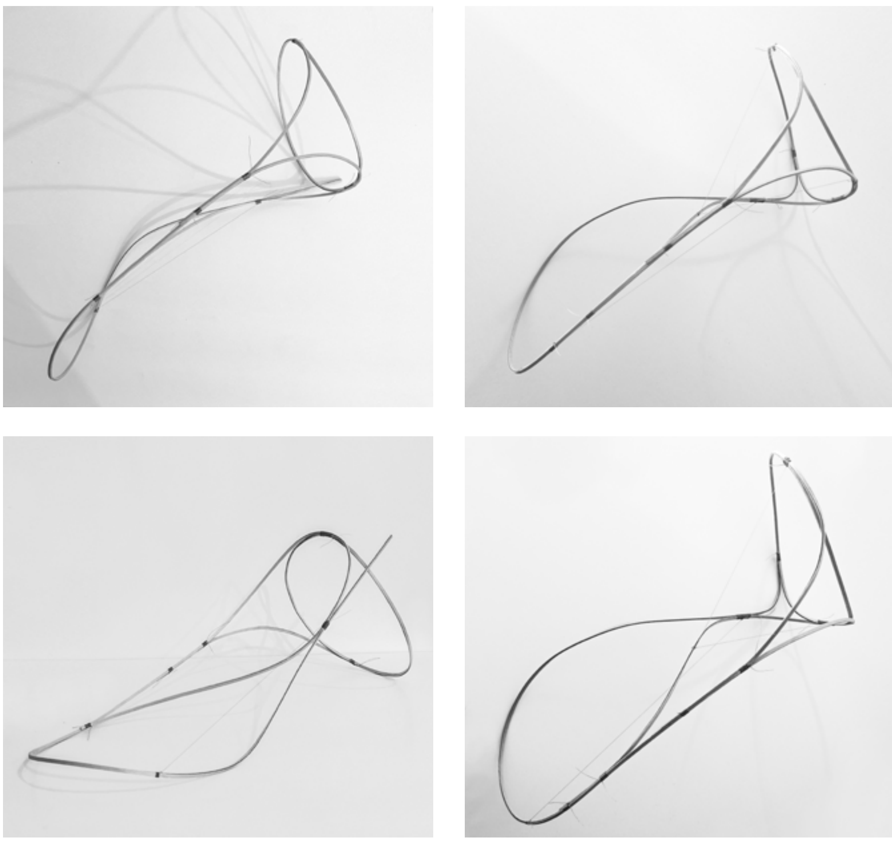
photo on the left side

FORM FINDING PROCESS

Different stages of the form finding process of the bearing structure of ***ARCOUSTICON*** are developed by using the active-bending method with strings as an elastic control mechanism and flexible wooden strips as a basic structural element.







photos © Tetyana Vovk, 2018 "ARCOUSTICON"

SP

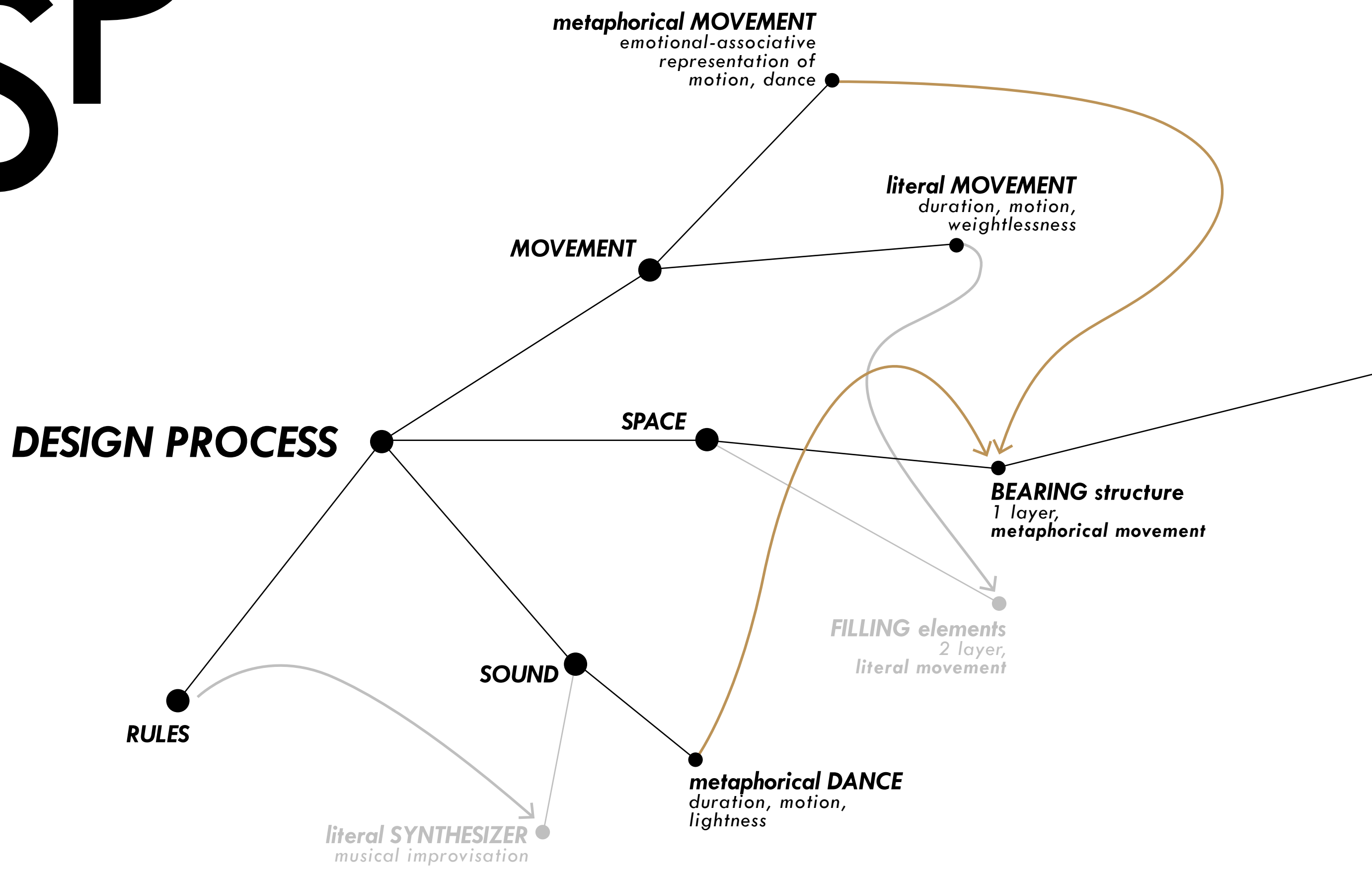
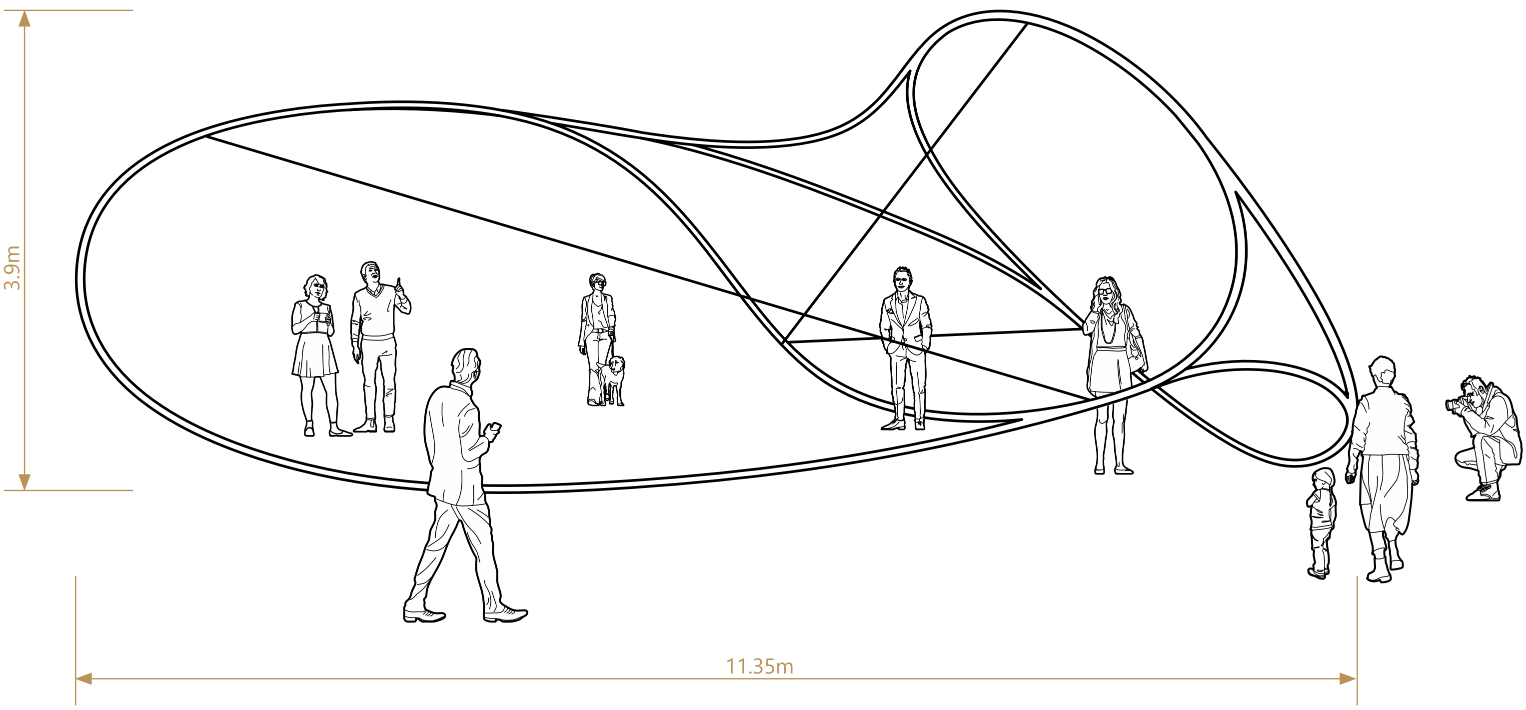


diagram SP8

basic structure elements

basic influence system

drawing SP1



PRIMARY FORM
physical structure
generated by using
bending-active approach

SECONDARY FORM
3d digital modell
of the primary structure

BENDING-ACTIVE STRUCTURE

The experiments of the form-finding process described above show that the bending-active structures can generate interesting and expressive forms.

The "spline" (wooden strip) as the main structural element is moving through space metaphorically, having a very clear association with dance and music. By implementation of such kind of bearing structures in the main form for the space-creating musical instrument we provide a very open kind of space. The structure works more like a frame, inviting the visitor to follow along its form.

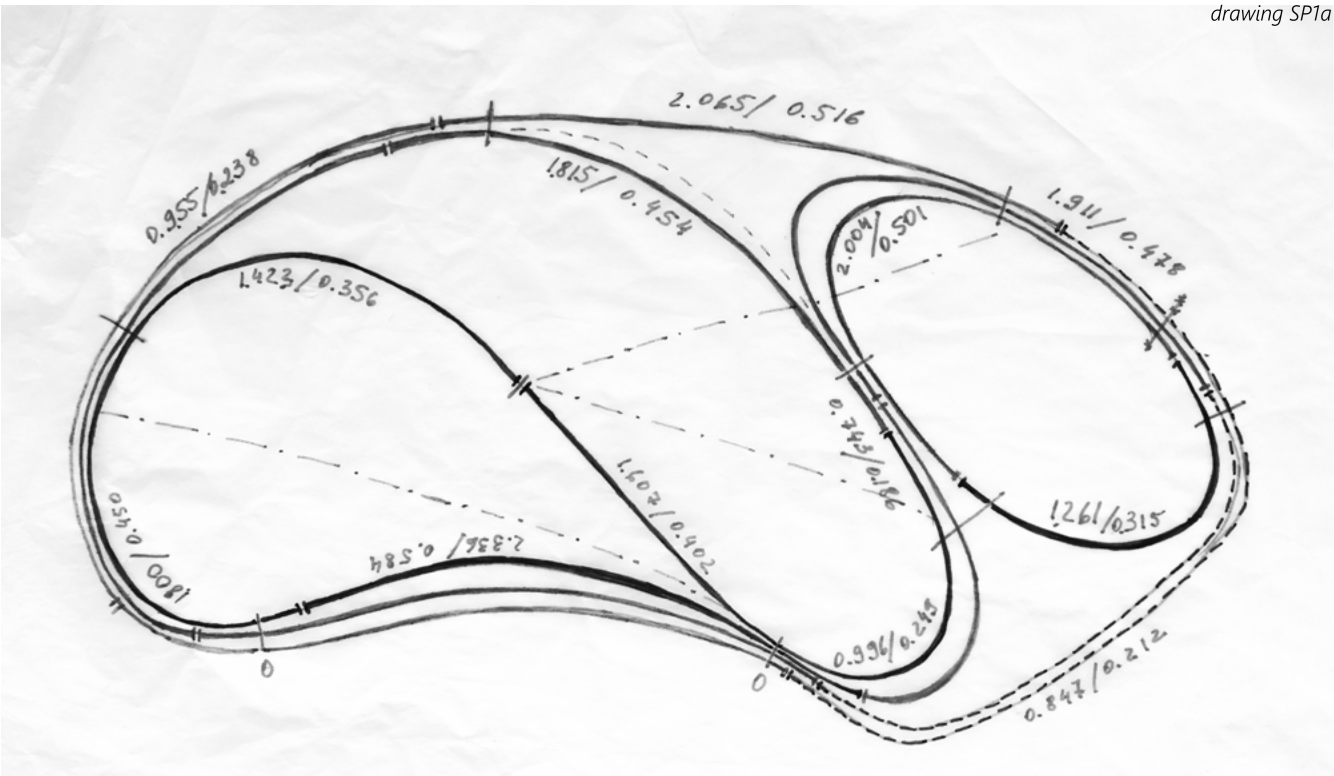
SECONDARY FORM

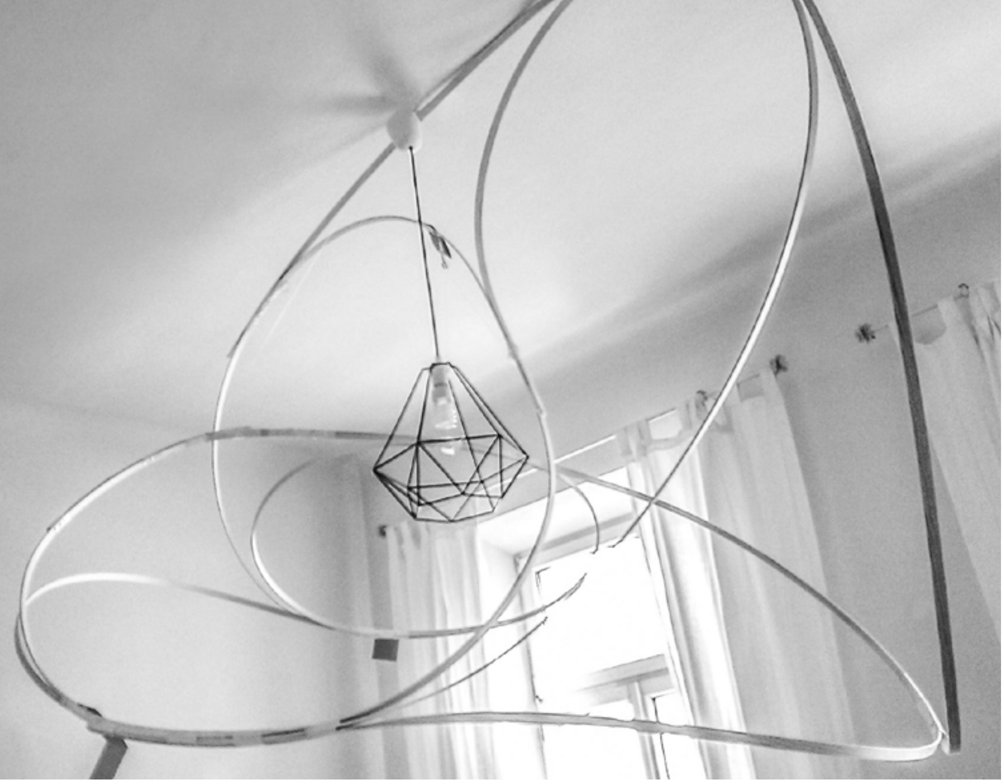
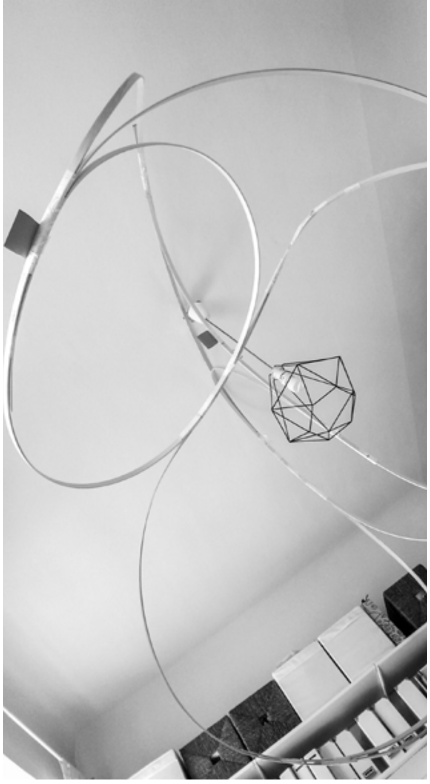
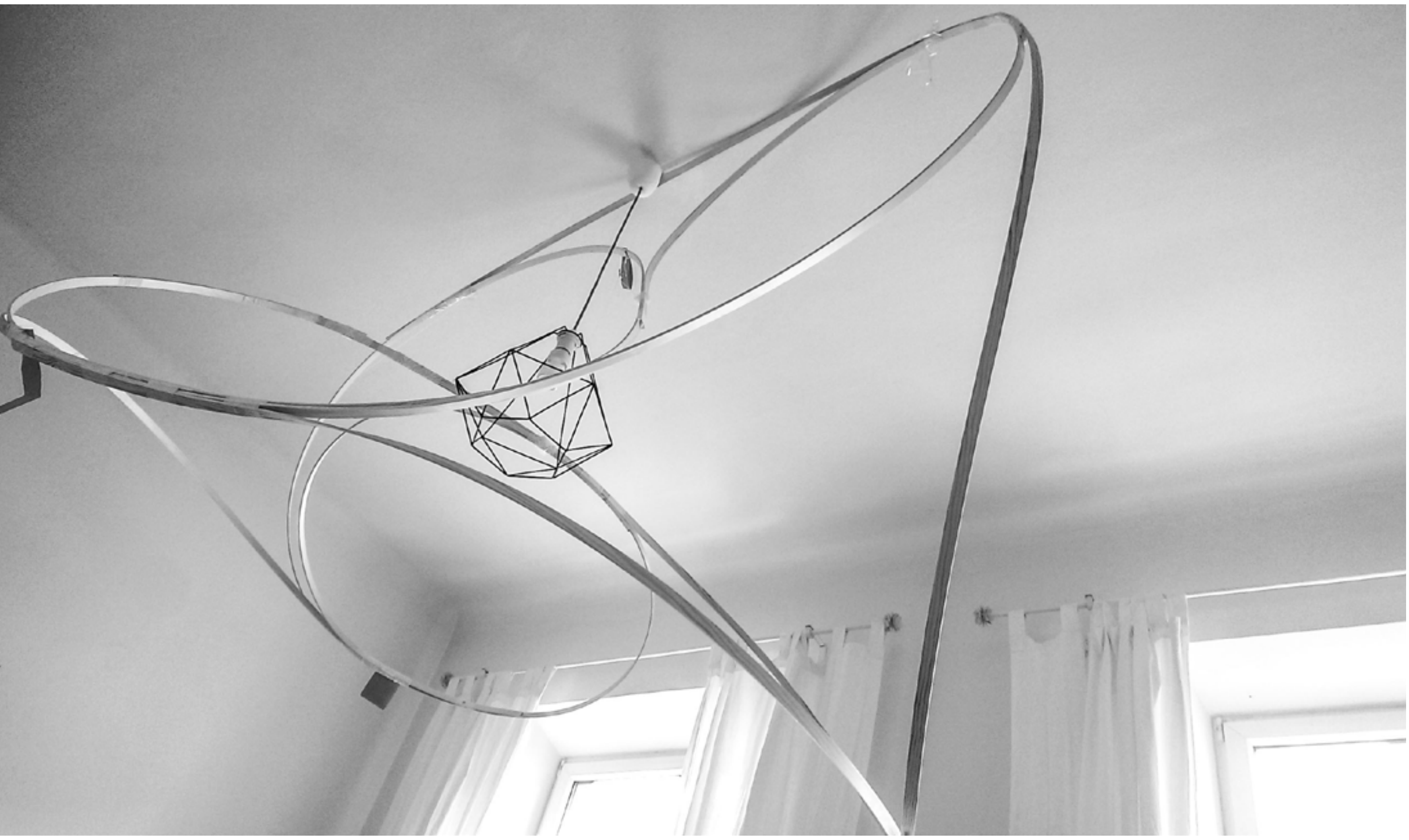
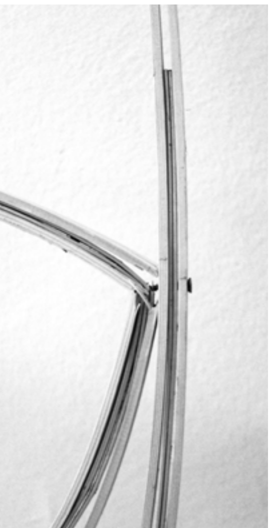
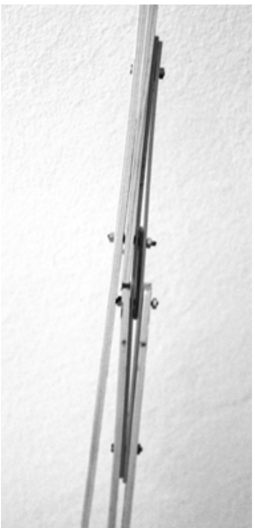
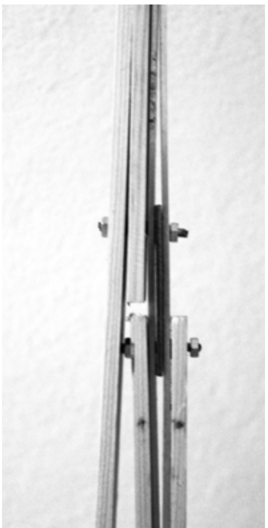
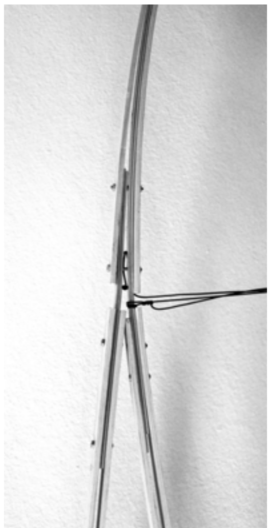
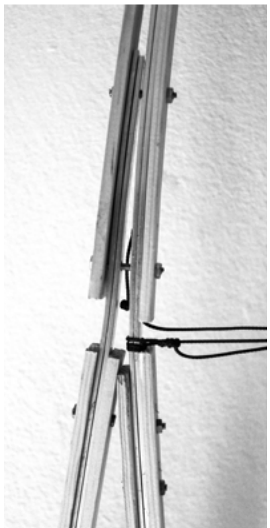
As a next step in the design process comes the approve of bending-active approach by the same model on a larger scale. For this step, base data of strips and strings length as well asplaces of its interconnections are needed. It is also essential to define the final size of the pavilion, what means scaling of the originally form.

That is why it is necessary to create a formal surrogat, in other words, a digital version of the primary structure.

The *drawing SP1* showes the 3d model with a final size of ***ARCOUSTICON*** and base length data to work with. *Drawing SP1a* is hand-made schema of main data for the next experiments.

drawing SP1a



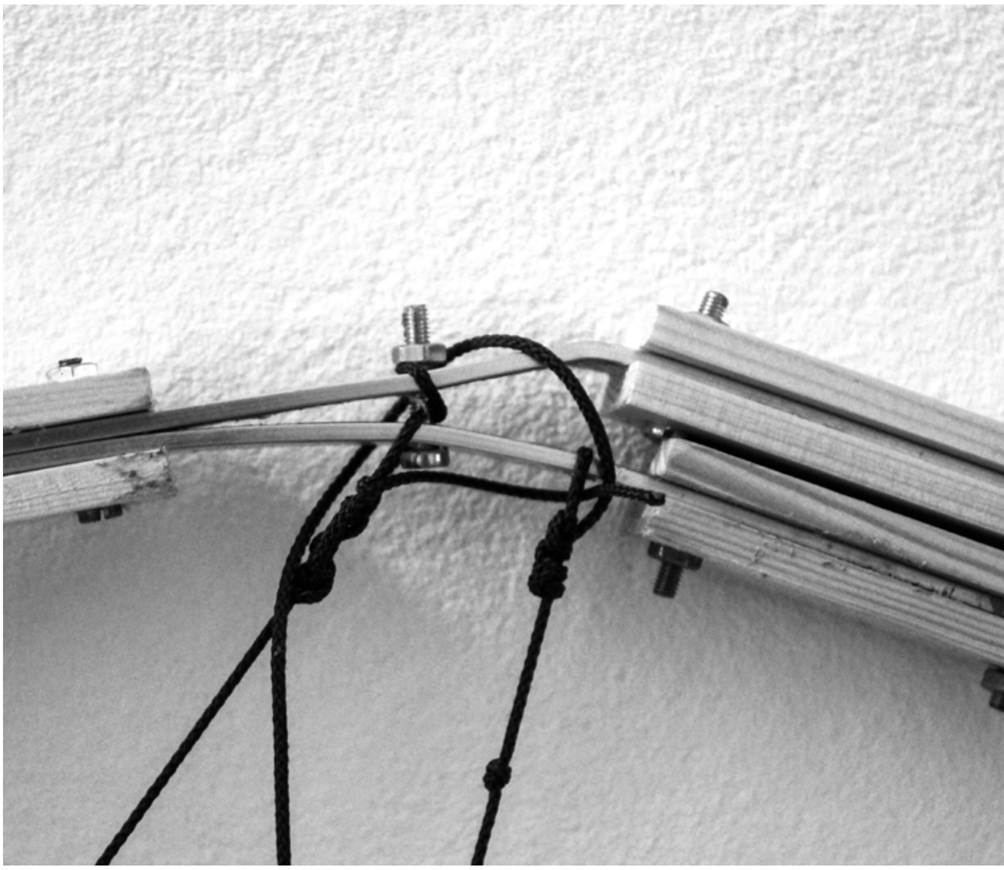
SPACE
1. LAYER

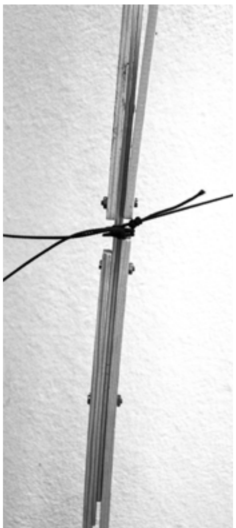
BEARING BENDING-ACTIVE STRUCTURE

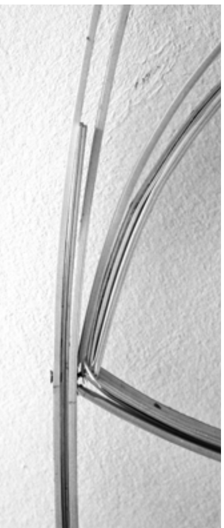
EXPERIMENT SP3
wooden structure
M=1:3

*photos "**experiment model SP3**"*

SP3







SPACE
1. LAYER

BEARING BENDING-ACTIVE STRUCTURE

EXPERIMENT SP4
aluminium structure
M=1:1

SP

SP4

CONCLUSION

As we can see on the photos of ***experiment SP3***, wood as the primary material does not work so well in a larger scale as it does in the smaller scale. The problem lies in the relaxation of the material, that influences the stress stiffening of the structural elments. Over time the stiffeners in the structural elements are slowly reduced, and this leads to deformation of the whole form, what is not desirable.

In the next experiment, I decided to experiment with aluminum tent poles, whose main function is a bearing function in bending active (tent) systems.

The photos on the left side show the attempt to go into the full structure size, in order to get a feeling of the created space.

photos on the left side

SPACE

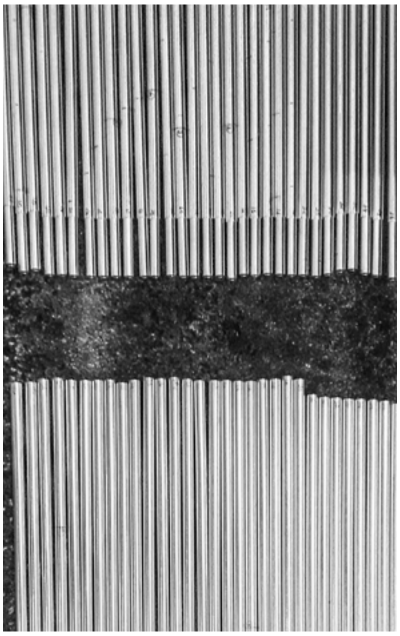
1. LAYER

BEARING BENDING-ACTIVE STRUCTURE

EXPERIMENT SP5

aluminium structure
M=1:3

SP5



photos "**experiment model SP5**" © Tetyana Vovk, 2018 "ARCOUSTICON"



photos © Tetyana Vovk, 2018 "ARCOUSTICON"

CONCLUSION

Summing up, the following conclusions can be drawn, based on the experiments described above:

1. bending-active structures work very well ina small scale. In principle there are three possible approaches to work with:

The first one is to use a simple structure type in a small size (tent structures). To go larger in size, a larger number of structural elements will be needed.

The second approach uses simple systems with a large number of structural elements. This allows the necessary control of the form and the bearing ability of the structure generally. In the design process, the first bent element defines the shape, and all elements are following this form, trying to reduce the stress (vernacular architecture, behavior-based approach).

The third approach is also about going into the larger structure size, but this time by using a complex structure for design. That means also more structural elements, but now they are working as one large system together, interacting with each other *(photo SP23 "Elastic Plastic Sponge" project)*.

2. All these approaches of the bending-active method, cannot work for the ***ARCOUSTICON*** structure.

The structure itself has to be a spline in space, without multiplication of its elements, as a pure thin form, as a metaphor of the dance trace, as well as a bearing layer for the next layers of elements (moving and musical tools).

3. Nevertheless, the bending-active approach is an excellent form finding method for this project.

This approach has a metaphorical connection with music not only in the pavilion's form but in the way of its creation.

The real tension in the structural elements corresponds with the physical and emotional tension of a dancer creating motion through space.

The form itself is a unique product of material possibilities, environment (temperature, humidity), and the present moment, where the author himself finds the thin boundary between the elastic body and the stress level.

We can also draw a parallel between the shape and the musical instrument. Materials and physical parameters of the medium cause slight variations between the expected and the actual form.

Parameters that determine the unique form of active bent structure, determine the uniqueness of the sounding of the musical instrument. The musical instrument receives its unique set of overtones, and also the tint of its sounding, first of all, from the features of the material.

SP

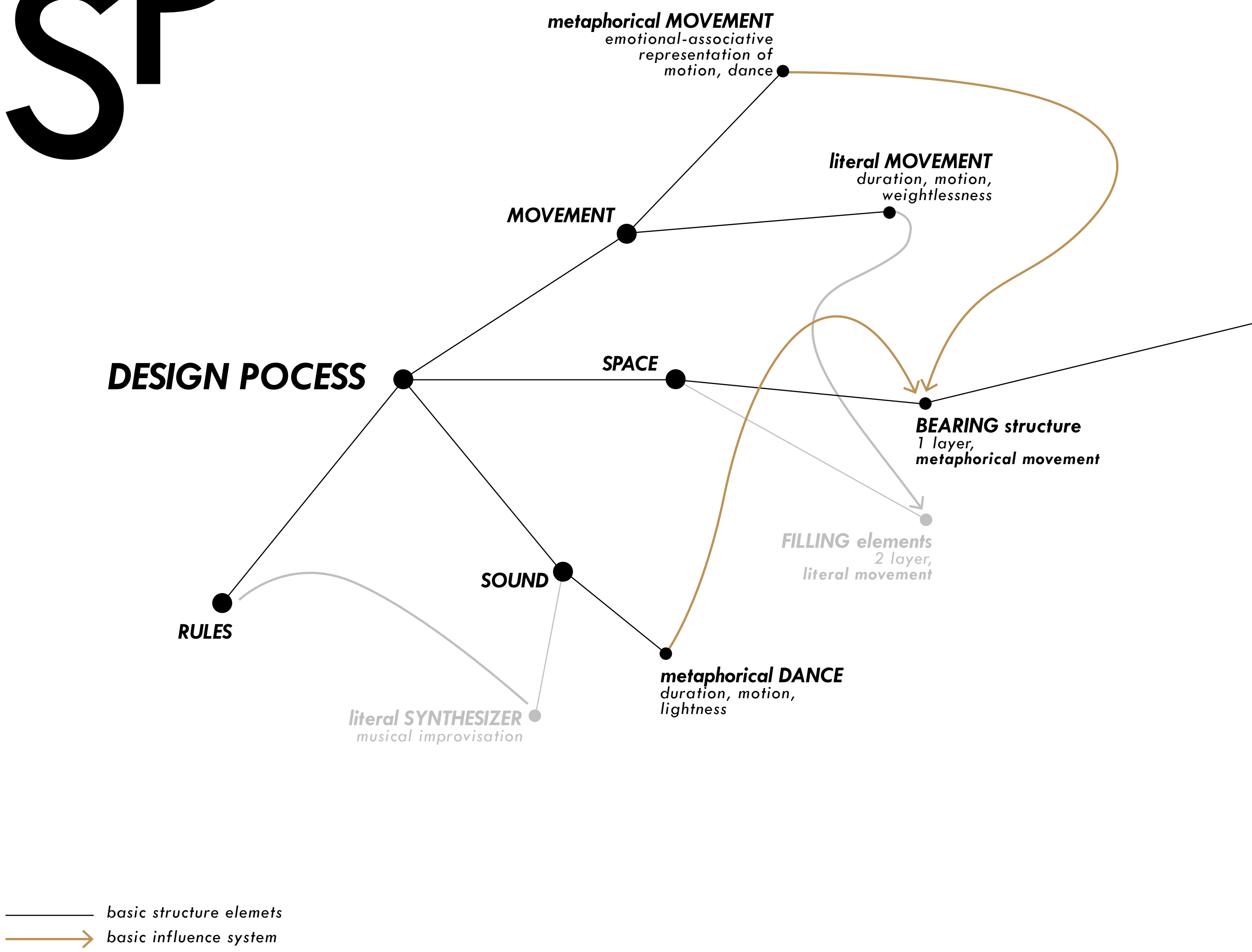


diagram SP9

SECONDARY FORM

The final bearing structure of ***ARCOUSTICON*** is designed on the basis of the primary model. The primary model was generated by the active-bending form-finding method, using a behavior-based approach.

SIZE AND MATERIAL

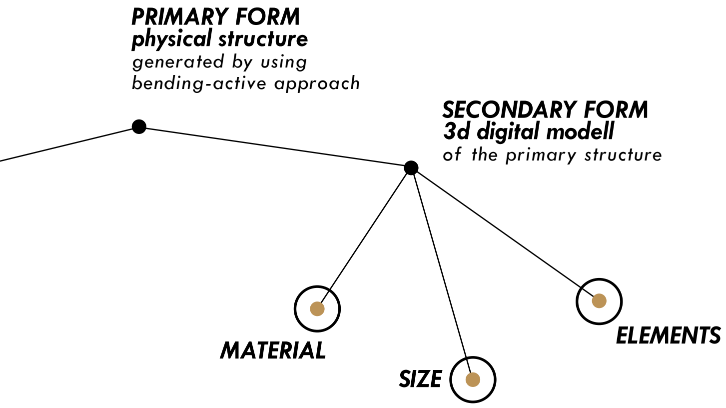
The size of the structure (10mx6mx-3.8m) is predefined in the previous section. (page 80) Generally, all data of the material and the design of the structural elements depends on static calculations. The main output parameter is to create a structure as thin as possible, nevertheless capable of withstanding the required loads and moments. In this project, the diameter of the structural tube needs to be at least 60,3mm with wall thickness 10mm. Material: structural steel S355 *(pages 98-101).*

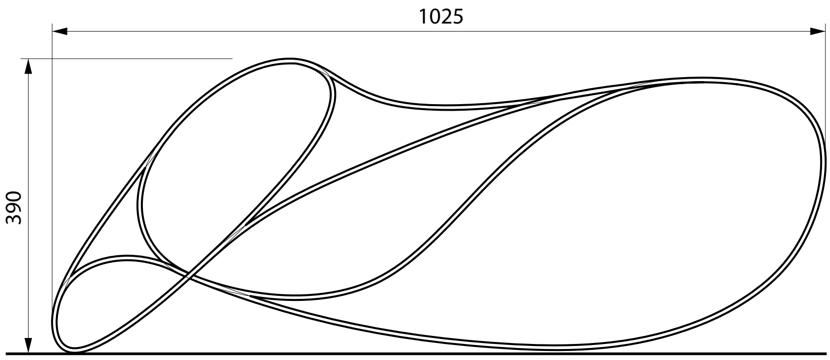
ELEMENTS

To provide possibility of transportation the structure needs to be divided into smaler constituent parts.

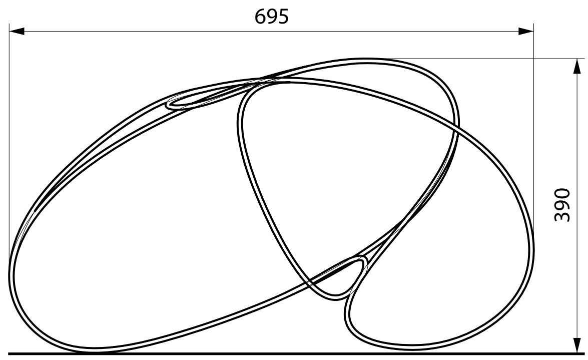
On the following *drawings SP3, SP5 (pages 94-96)* this division can be seen. The structure (first layer) consists of 16 simple elements and 7 complex elements. The complex elements consist of few(2-4) tubes, pre-welded together. Simple elements consist only from one tube. On the *drawing SP6 (page 97)* we can see a detail of its connections.

DESIGN PROCESS



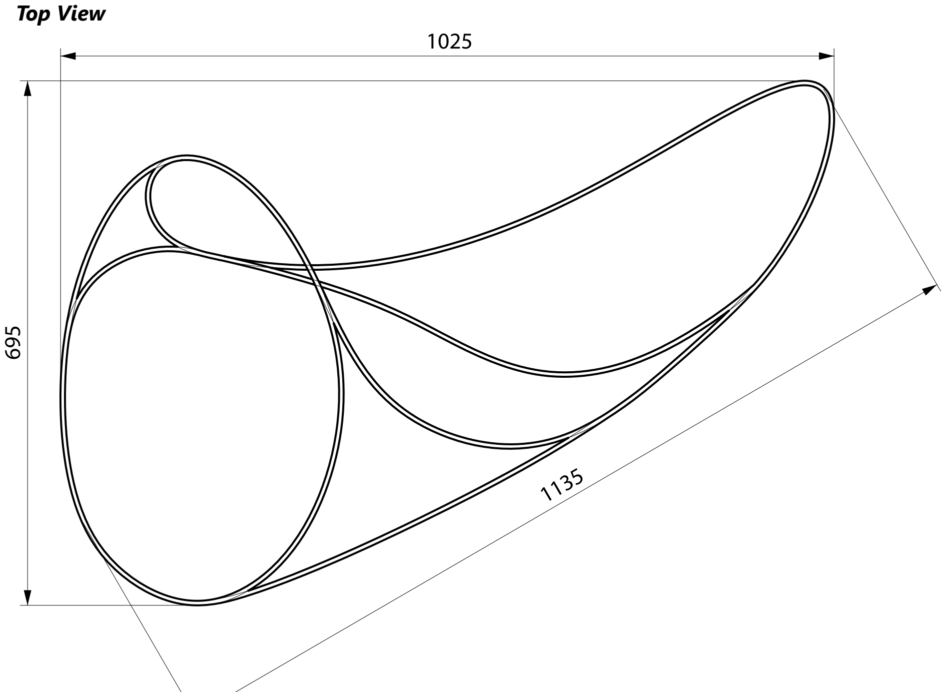


Front View



Side View

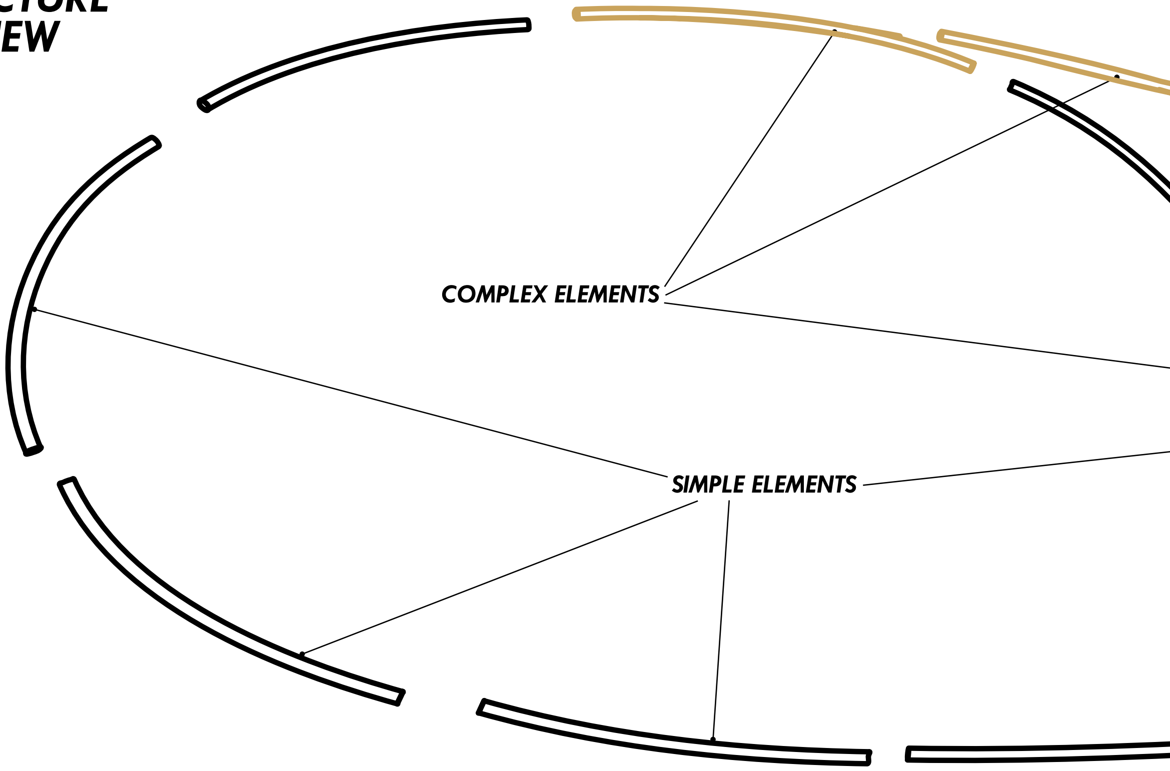
Top View



drawing SP2
Front View, Side View, Top View
M=1:100

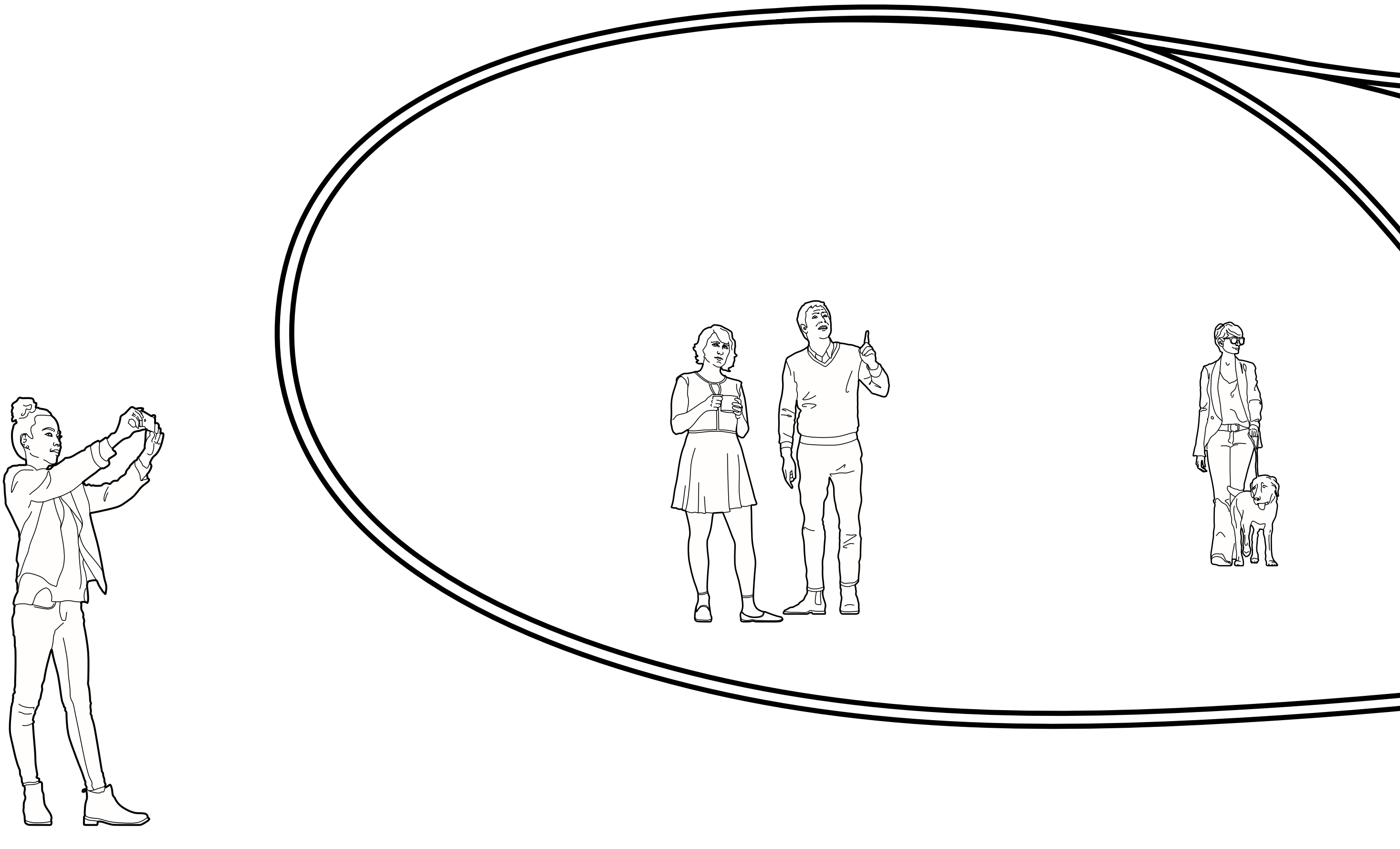
1.LAYER
BEARING STRUCTURE PERSPECTIVE VIEW

STRUCTURAL PARTS
DRAWING SP3

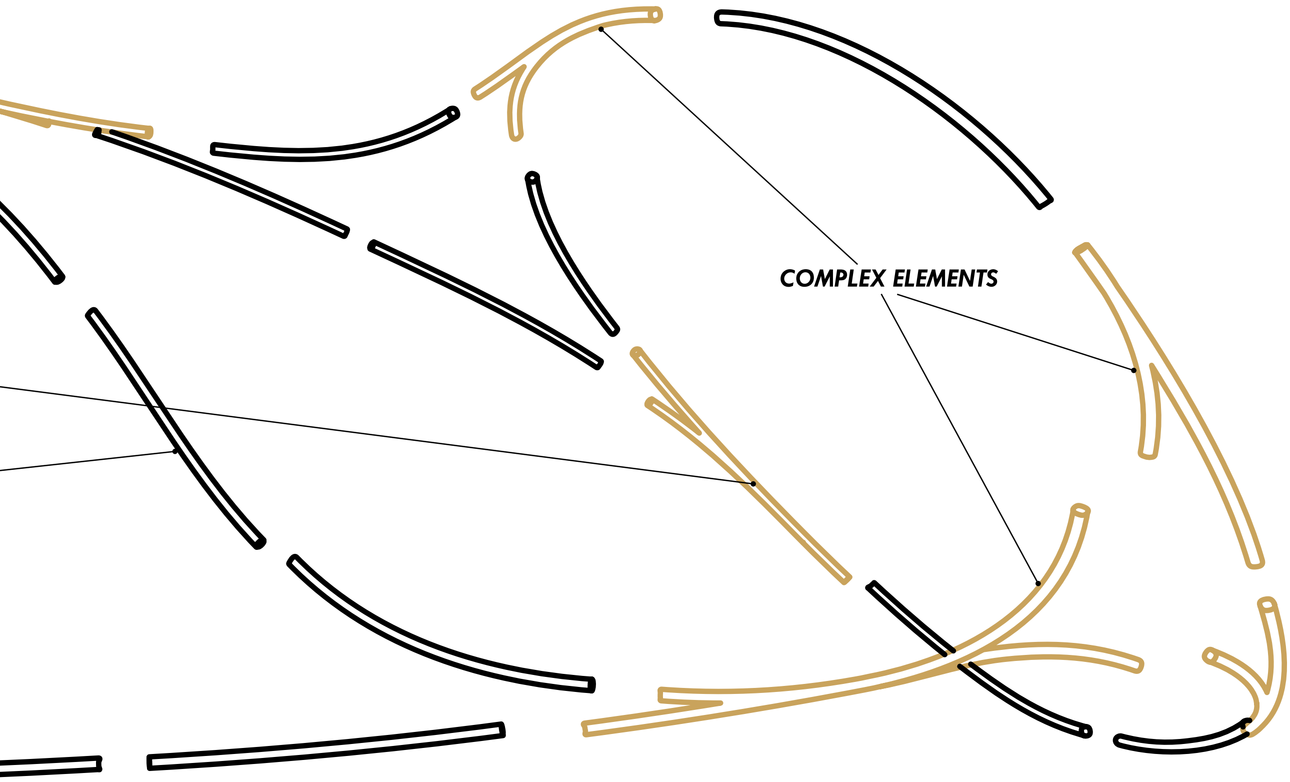


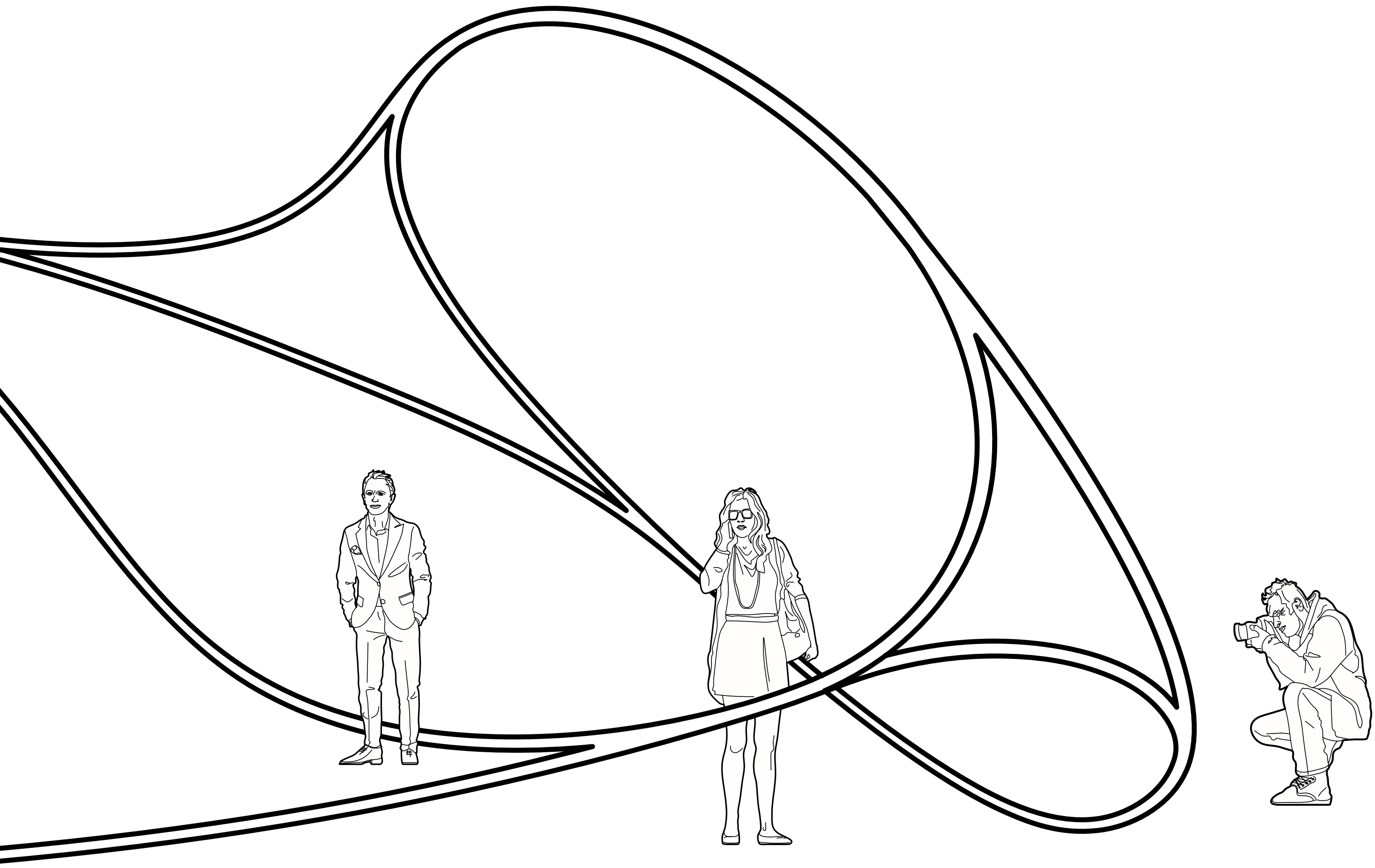
1.LAYER
BEARING STRUCTURE PERSPECTIVE VIEW

DRAWING SP4



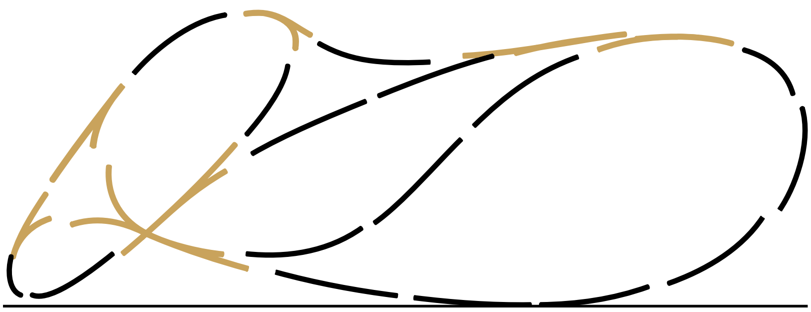
DESIGN PROCESS



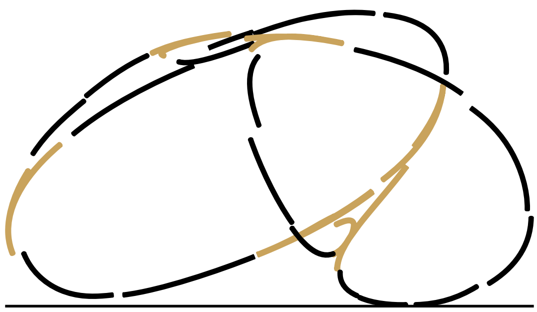


1.LAYER
BEARING STRUCTURE PERSPECTIVE VIEW

STRUCTURAL PARTS
DRAWING SP5
FRONT VIEW, SIDE VIEW, TOP VIEW



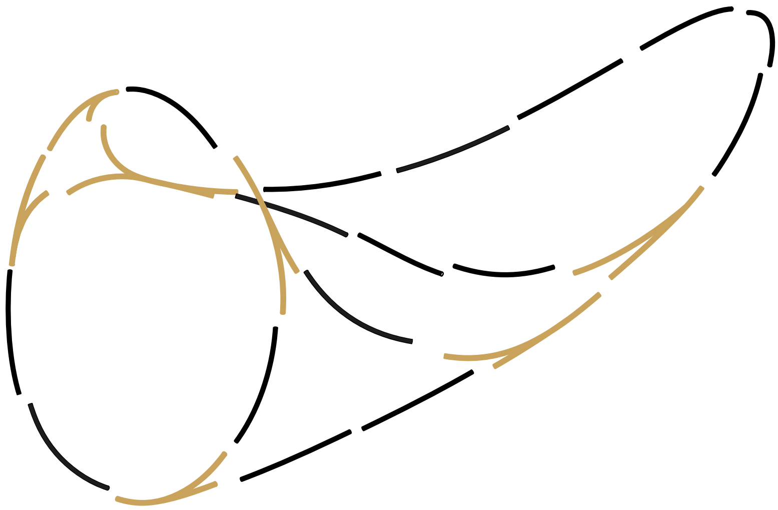
Front View



Side View

simple elements
complex elements

Top View

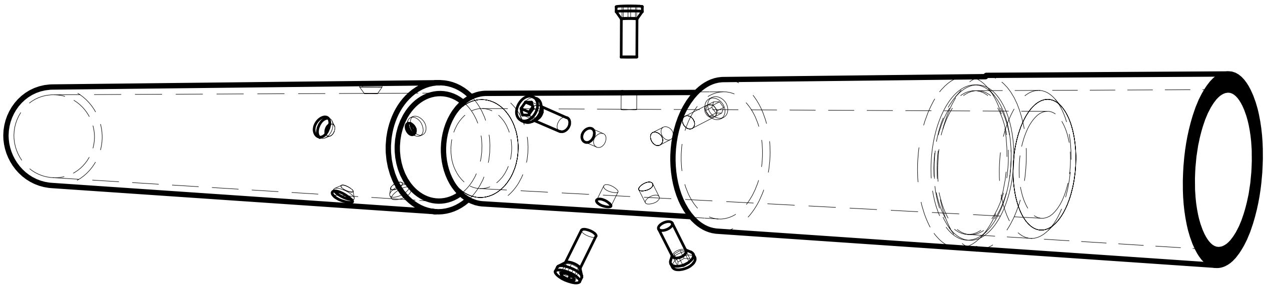


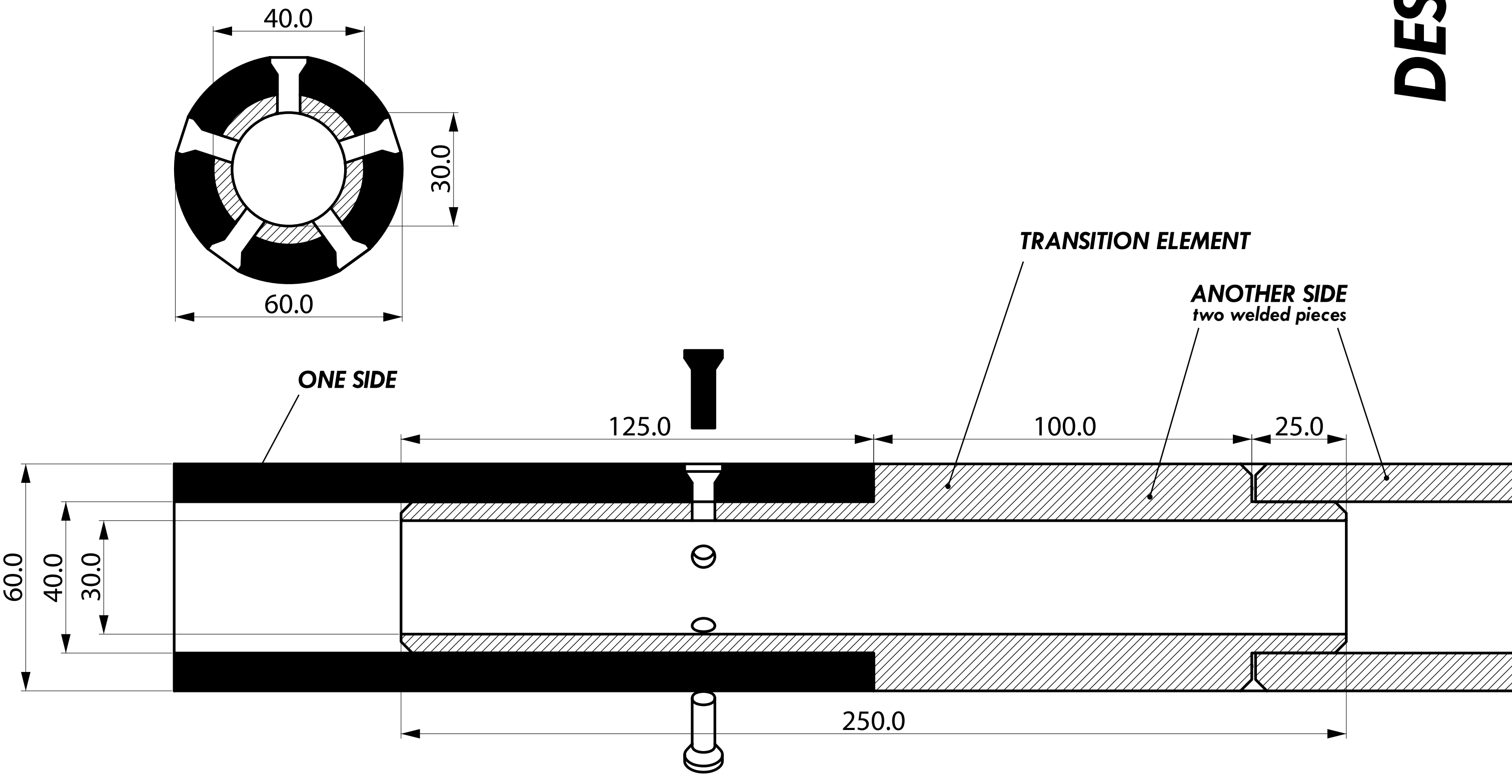
STRUCTURAL PARTS

The 1. Layer of bearing structure consists of 16 simple elements and 7 complex elements *(drawing SP5).*

The connection detail is designed to evenly transmit the stress in the body, as it happens by welded structures. Similar structure connections are used in smaller scale by active-bended tent structures (aluminum or fiberglass tent poles).

The 3D model of the structure will be sent into a pipe-bender company





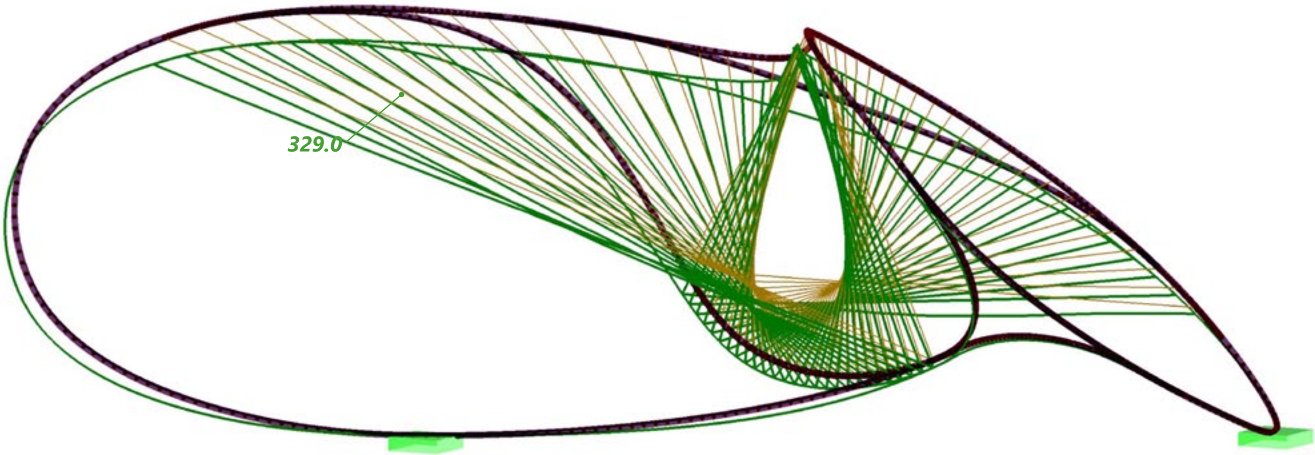
(for example *pemat* company) that can produce the elements already in right form and necessary length (l=2-2,5m). By complex elements, all pipe parts will be welded together into one piece (drawing SP5).

To the one side of the pipe is welded transition element with a smaller diameter on one side. So with 5 bolts, two parts can be connected together *(drawing SP6).*

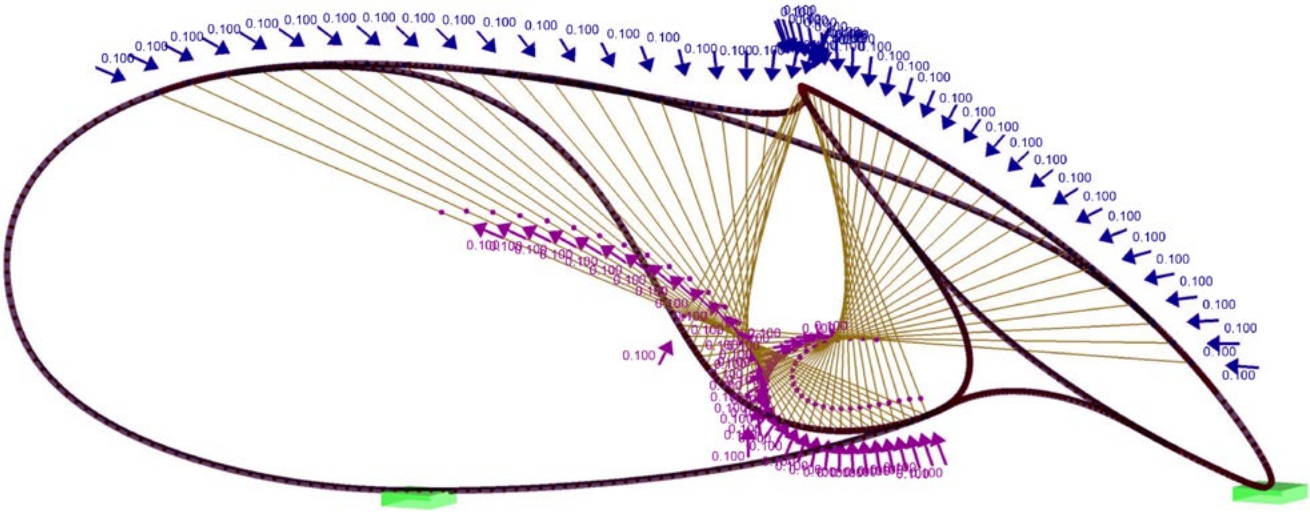
STRUCTURAL PARTS
DRAWING SP6
LONGITUDINAL SECTION
CROSS-SECTION
M=1:2

1.LAYER
BEARING STRUCTURE
PERSPECTIVE VIEW
STATIC CALCULATION

DRAWING SP7
GLOBAL DEFORMATIONS
Max: 329.0, Min: 0.0 [mm]
Factor for deformations: 1.00

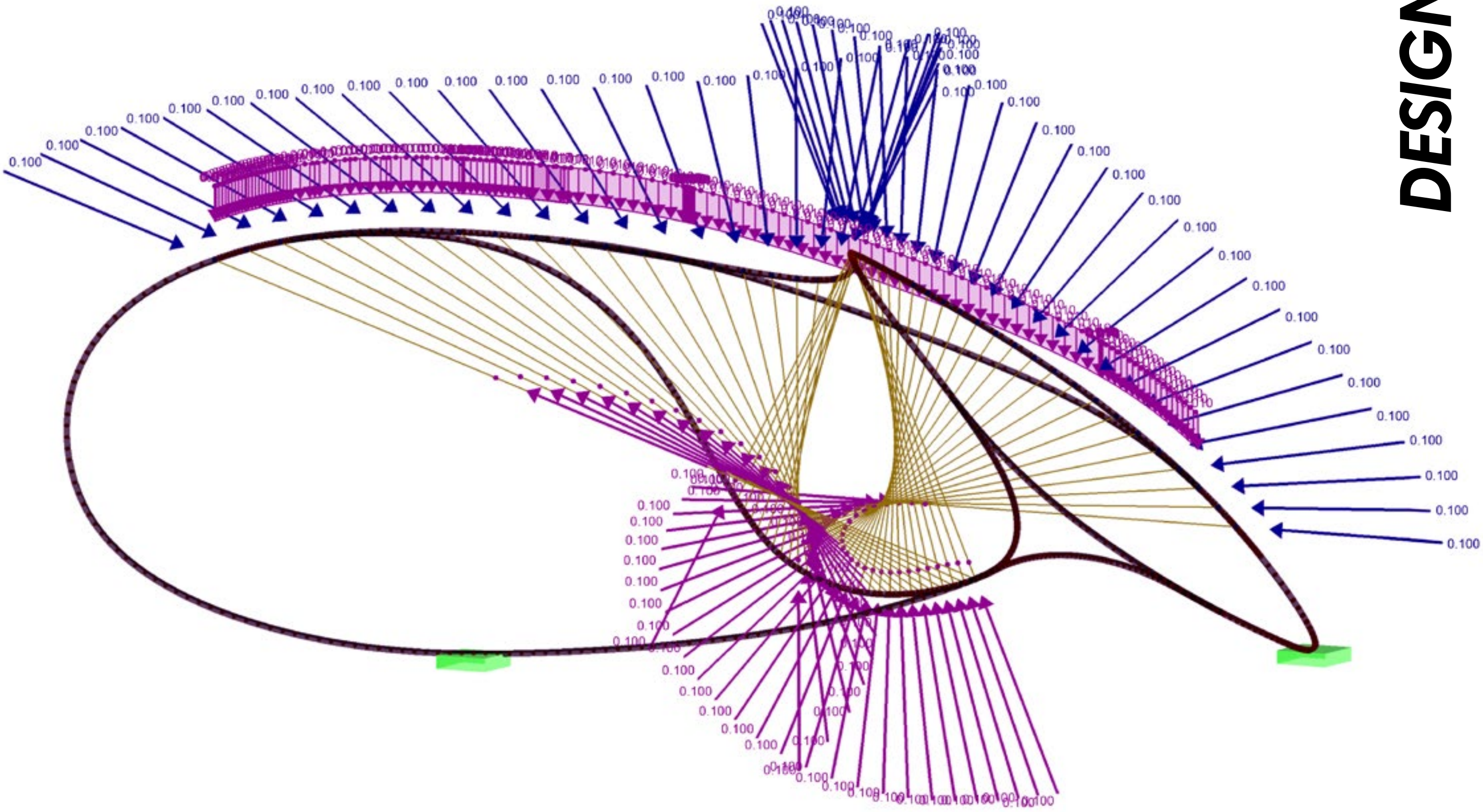


DRAWING SP9
LOAD, MUSICAL TOOLS [kN]

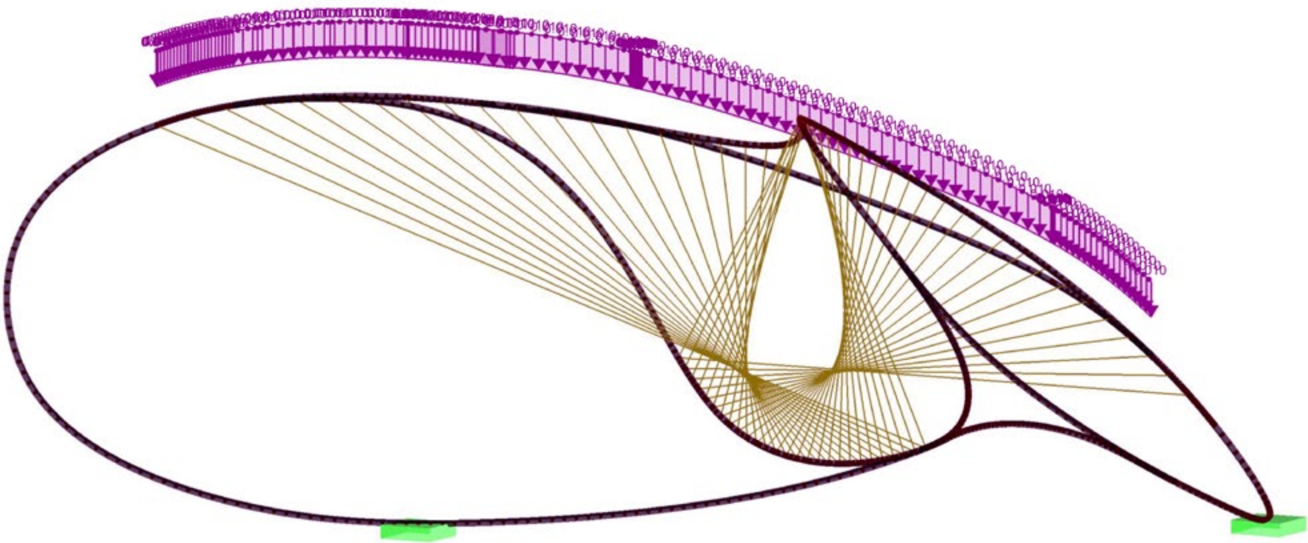


Static Calculation by Andrii Vons

DRAWING SP8
GLOBAL LOAD [kN], [kN/m]



DRAWING SP10
LOAD, MOVING TOOLS [kN/m]



Static Calculation by Andrii Vons

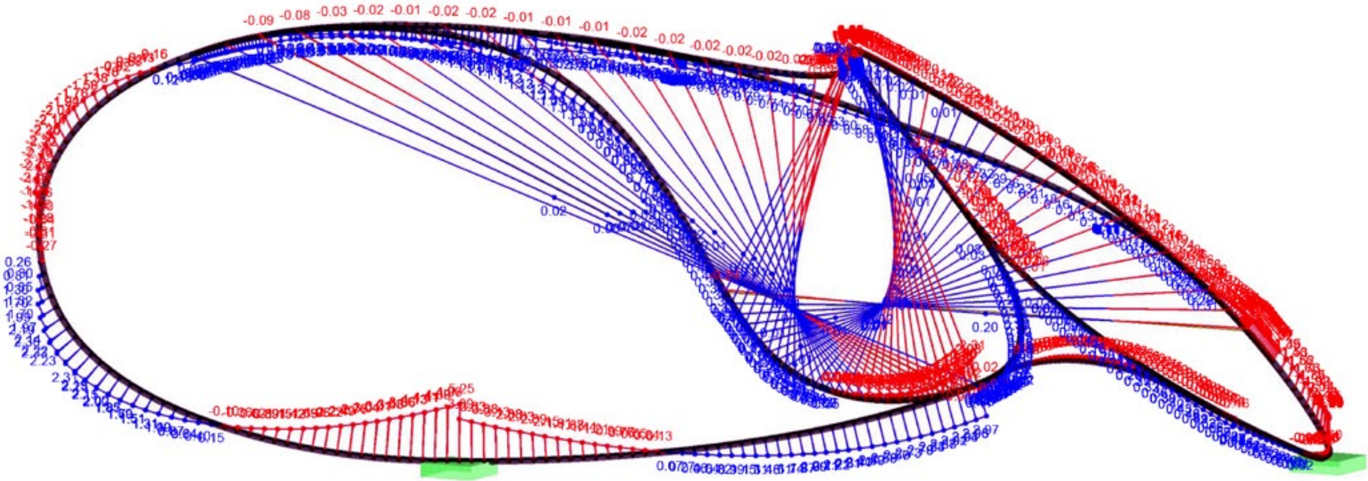
1.LAYER

BEARING STRUCTURE
PERSPECTIVE VIEW
STATIC CALCULATION

DRAWING SP11

INTERNAL FORCES M-Y

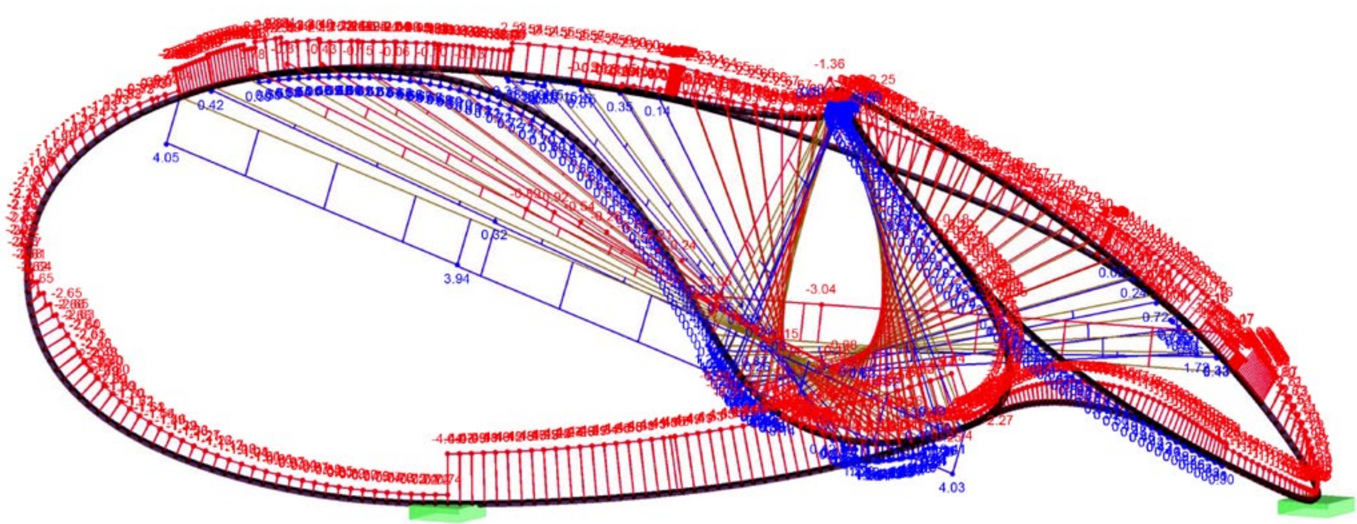
Max M-y: 2.97, Min M-y: -5.25 [kNm]



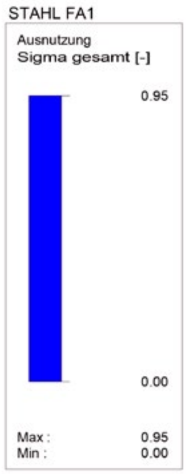
DRAWING SP12

INTERNAL FORCES N

Max N: 4.05, Min N: -4.63 [kN]

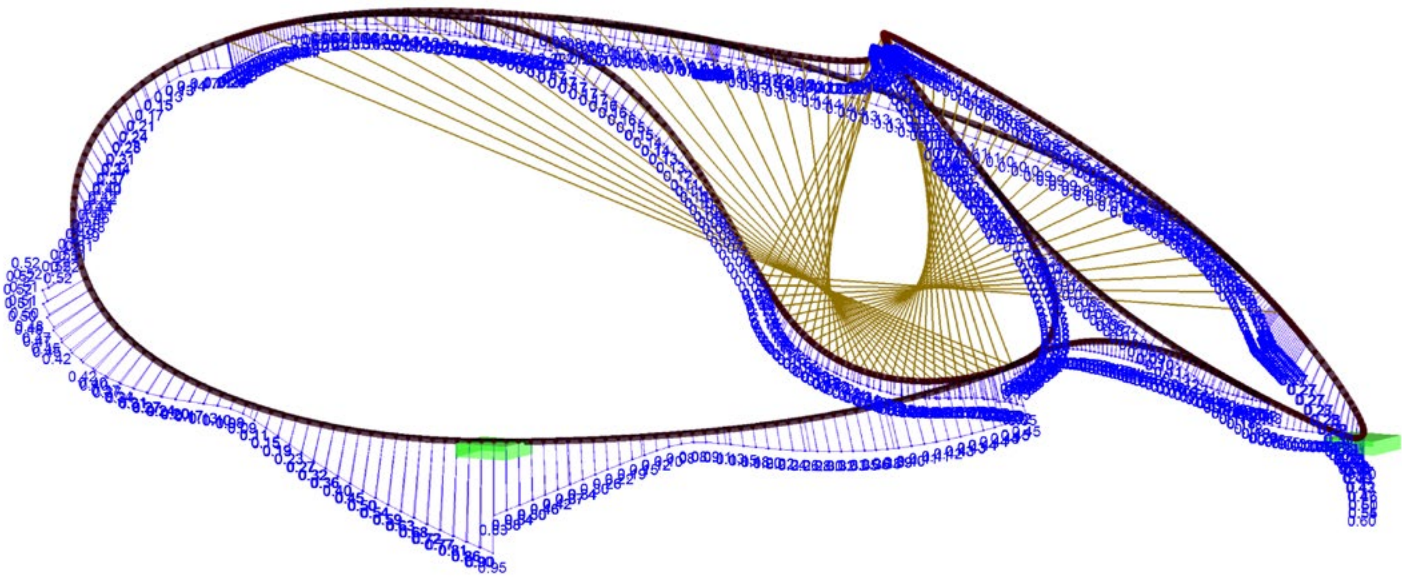


Static Calculation by Andrii Vons

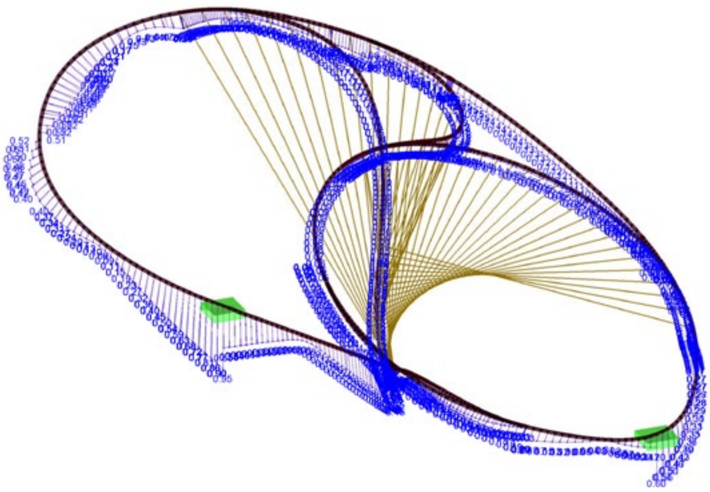


DRAWING SP13
Max Sigma total: 0.00, Min Sigma total: 0.00

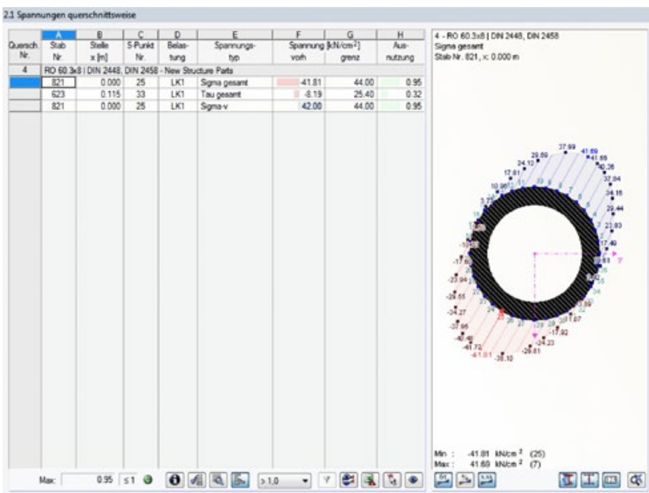
Sigma - Stress Ratio,
percentage of metal strength use



DRAWING SP14
Max Sigma total: 0.00, Min Sigma total: 0.00



DRAWING SP15
Sigma total, Stab Nr. 821, x:0.000m
DM=60.3x8mm



2.1 Spannungen querschnittsweise

Quersch. Nr.	A Stab Nr.	B Stelle x [m]	C S-Punkt Nr.	D Belas-tung	E Spannungs-typ	F Spannung [kN/cm²] vorh	G grenz	H Aus-nutzung
4	RO 60.3x8 | DIN 2448, DIN 2458 - New Structure Parts							
	821	0.000	25	LK1	Sigma gesamt	-41.81	44.00	0.95
	623	0.115	33	LK1	Tau gesamt	-8.19	25.40	0.32
	821	0.000	25	LK1	Sigma-v	42.00	44.00	0.95

Max: 0.95 ≤1

Static Calculation by Andrii Vons

photo © Tetyana Vovk, 2018 "ARCOUSTICON"

LAYER 2 filling elements

STRING-SHOOTER as a real-time movable tool

SP

2. LAYER
FILLING ELEMENTS
LITERARY MOVEMENT
STRING-SCHOOTER

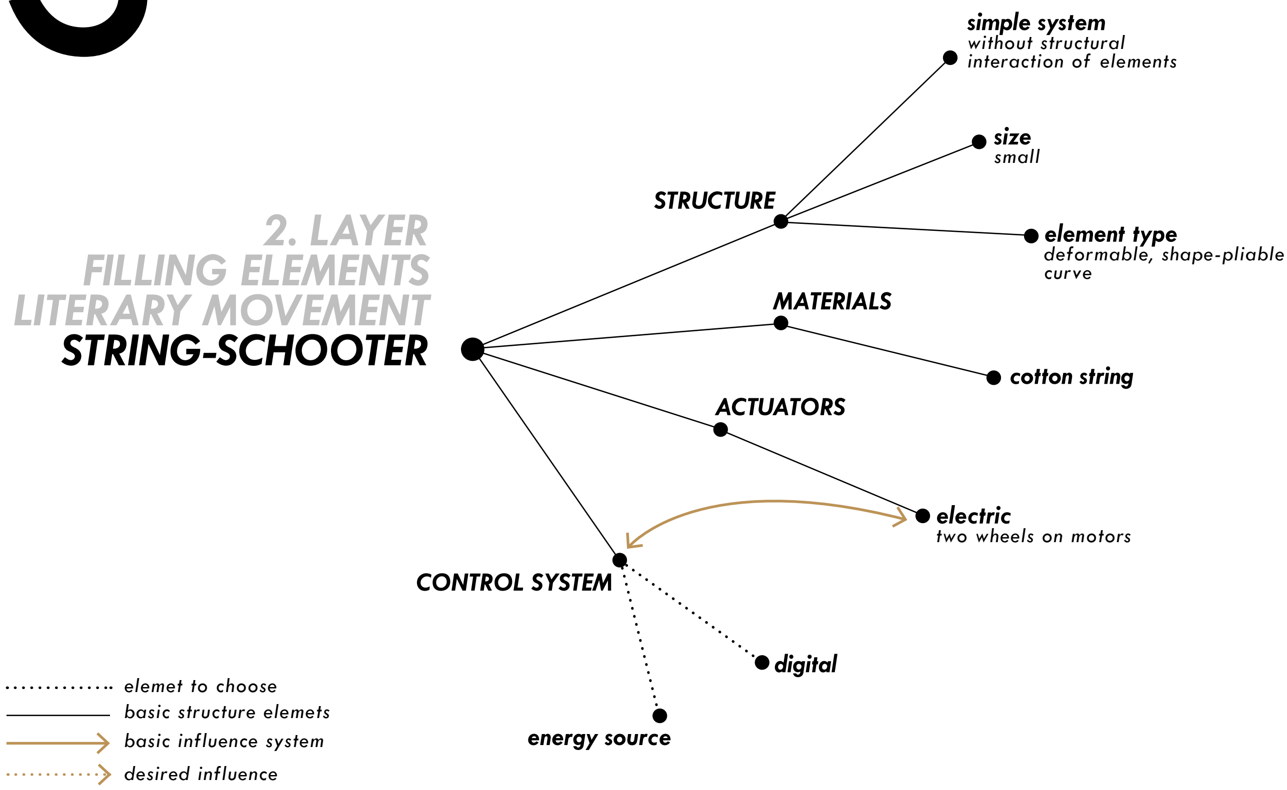


diagram SP10 "**string-shooter system**"

In a search for a lightweight moveable structures, that could be used as filling interactive elements in the ***ARCOUSTICON*** design, a variety of Lariat Chain system[1], that has no official name, but is affectionately called as a "string shooter" caught my attention.

1 *"Lariat Chain" is an Artist-in-Residence project at the Exploratorium in San Francisco 1986, created by Norman Tuck.*

"... uses a motorized chain - lightweight and safe in supervised little hands - that moves continuously. A touch changes its regular pattern of movement. A viewer can either appreciate that the piece represents 'the phenomenon of the standing traveling wave' - or stand and enjoy the mesmerizing visual treat of the dancing chain."
Carr, Genie (1986) in The Winston-Salem Journal

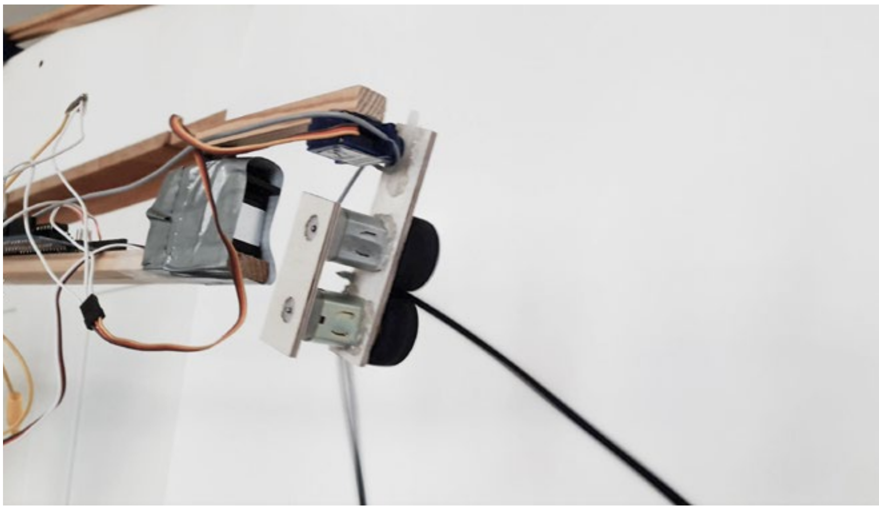
STRING-SHOOTER

The String-shooter system is based on the principles of baseball launcher machines. The system consists of two wheels on motors (actuators) and string-loop as a movable element, capable of generating different forms and slow-motion ("freezing") effect. This phenomenon occurs due to appearing transverse waves in the string.

"The speed of waves through a stationary rope can vary due to the tension and the density of the material. What happens when the rope itself is put into motion and then a wave disturbance is added. This idea is the start of our investigation using a few different loops of ribbon and rope. The ropes are made into loops by melting and joining the two ends together and then hang limply until put into motion. The behavior of the rope as it hangs stationary and limp versus when it is put into motion is quite remarkable.

The closest analogy that might help to understand what is going on would be to imagine throwing rock in a moving stream or river. The waves traveling upstream would slow down and if the stream would be fast enough, the waves wouldn't be able to move in that direction at all. The waves headed downstream would move very fast since both speeds would be in the same direction."

Bruce Yeany, via thekidshouldseethis.com, "A homemade string shooter & slow-moving waves in rope", last view: 04.10.2018



photos ***"experiment SP6"*** *© Tetyana Vovk, 2018, "ARCOUSTICON"*

At the photos above, showed the first experiment experience with this kind of movable structure *(experiment SP6)*. For the future design, I decided to expand the spectrum of possibilities and add to a typical string-shooter model two degrees of freedom. Thus, the first one provides a vertical rotation of the system, and the second one horizontally.

In the experiments with a string-shooter, another phenomenon, known as chain fountain phenomenon has become apparent.

If the string(rope), in the string-shooter system, during the movement is directed vertically, at the moment when the rope touches the floor, she rises up above the wheel level.

J. S. Biggins and M. Warner described this phenomenon in "Understanding the chain fountain", 2014, the Proceedings of the Royal Society, in the next way: "...*We show that the formation of a fountain requires that the beads come into motion not only by being pulled upwards by the part of the chain immediately above the pile, but also by being pushed upwards by an anomalous reaction force from the pile of stationary chain...*"

In the case of string-shooter, we are using a rope, not a chain, but the phenomenon still stays the same. The rope is not consists of parts, but also make this kind of fountain. That means that the chain fountain is not formed by "*parts pushed upwards by an anomalous reaction force from the pile of stationary chain*".

During the experiments, it was possible to observe that the formation of this phenomenon depends on some support (floor) under the rope. As soon as rope touches this support, its upper part rises upwards.

SP

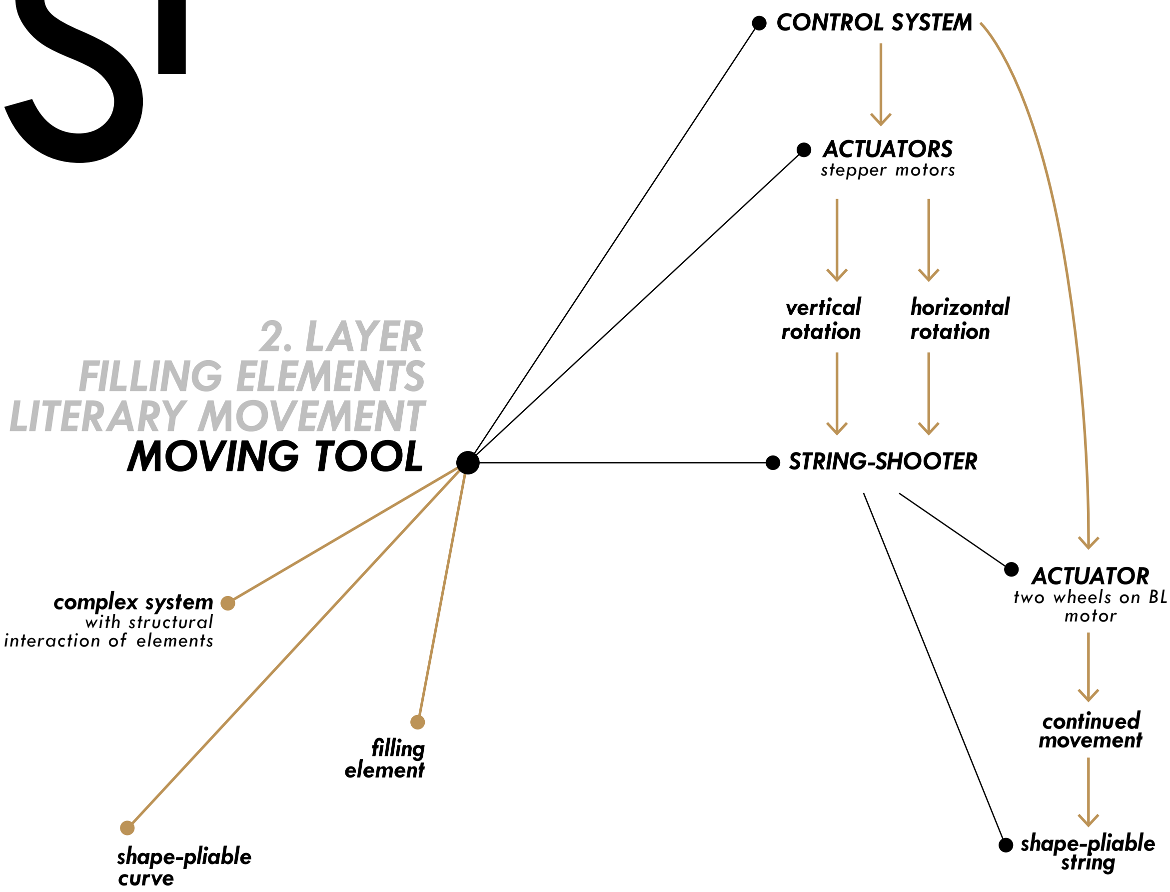


diagram SP11 "***moving tool***"

The filing elements in the project are ***MOVING TOOLS***. The moving tool is a complex structure of ***robotic hand*** and ***string- hooter system*** as the element to be move. *diagram SP11*

The hand consists of two parts that proveid horizontal and vertical rotation *(2 degrees of freedom)*. Two actuators *(stepper motors)* put it into action.

The string-shooter itself consists of two wheels on motors and string-loop as a shape-pliable movable element.

Motors and string are ***central elements which have a global impact*** on the final sound visualiation.

MOTORS
STRING-SHOOTER

There are a lot of different types of motors, with different properties, structures, and system of control. For the first experiments with the string-shooter, was used Brushed DC electric motor (***experiment SP6***).

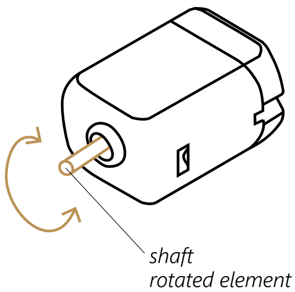


diagram SP12 "**DC electric motor**"

In this size, I found the motors optical to large for the implementation in movable tool structure.

The *photo SP31* shows the prototype of the system with smaller motors, ***experiment SP7.*** Unfortunately, in such a size, the power of motor was too small to put the string into the motion.

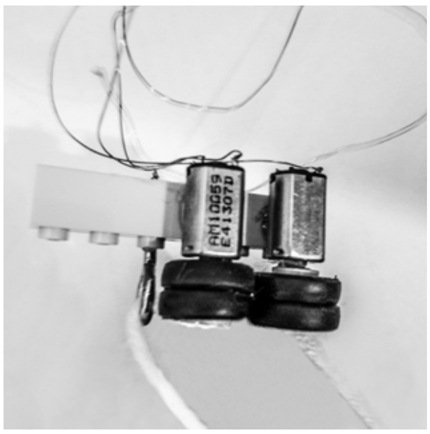


photo SP31 "**experiment SP7**"

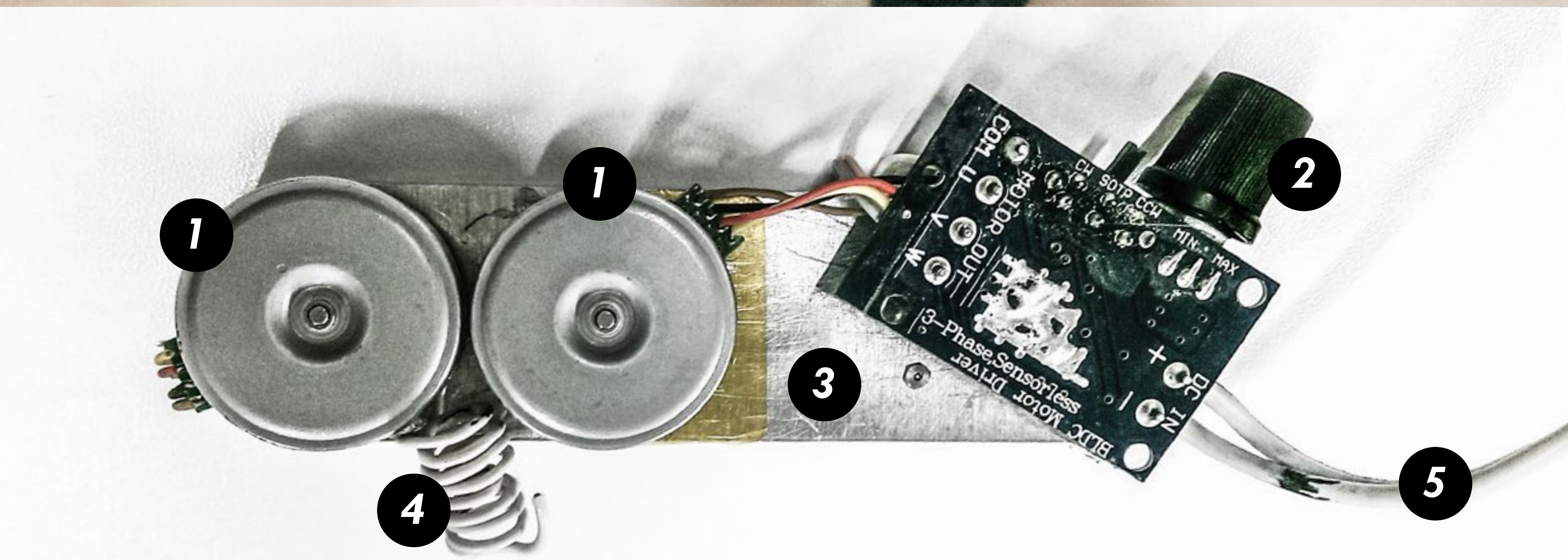
There was a question of finding the ***optimal size and power*** of the motor.

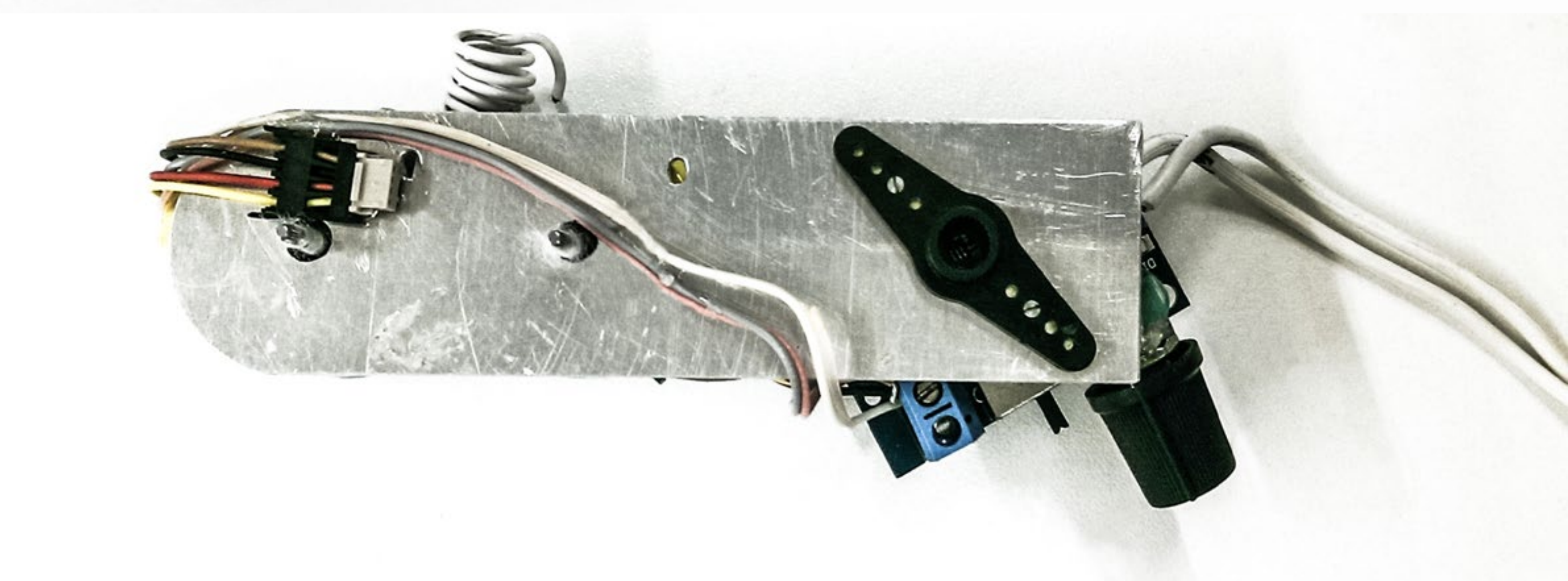
The significant thickness of the string-shooter design makes wheels, that are attached to the moving shaft of the motors (actuators). Taking this into consideration, the idea of reducing this thickness by ***combining together*** those elements (placing the motor in the middle of the wheel) *photo SP32,33* ***experiment SP8*** came to mind.

For this experiment, the same type of motors was chosen (Brushed DC electric motor) but in the other form and size. The surface of the motor is wearing a case, attached only to its rotating shaft. Unfortunately, this type of motor was also too weak to drive the metal case and the string into the motion. But the idea of designing the motors and wheels as one structure element was right, by such an approach the system looks smaller and cleaner. It is needed to be realized in the **"*moving tool*"** design.

photo SP32 "***experiment SP8***"

photo SP33 "***experiment SP8***"


1
1
2
3
4
5
BLDC Motor Driver
3-Phase,Sensorless
MOTOR_OUT
DC IN
MIN
MAX



SPACE
2. LAYER

STRING-SHOOTER

EXPERIMENT SP9

SP

SP9

1 The other type of motor
BL electric motor (M29BL)

Essentially, the main difference between brushed and brushless motor is in way of current transfer.

In the brushed motors (described above) this transfer happens mechanically via metallic brushes. But by the brushless motor, the rotor is turned electronically. It is directly reflected in the structure of the motor itself, due to which its outer shell moves and it shaft stay stable (*diagram SP13).*

So the problem of motor and wheel combination is solved, in the way that the outer shell of a motor at the same time is a wheel.

2 ***BLDC motor driver***
The BL motor has fixed magnets on the rotor and the coils in the cabin. Each surrounding coil in series repulses and attracts the fields of the fixed magnets. The coils need to be kept synchronized with fixed magnets, so the magnetic fields are in opposition, and the rotor keeps turning. The current must pass through each coil at a particular moment. The control of the process provides a microprocessor or electronic controller *(a motor driver)*. In this experiment was used sensorless back EMF sensing control.

3 ***base plate***

4 ***string guide tube***

5 ***source of energy (12V)***

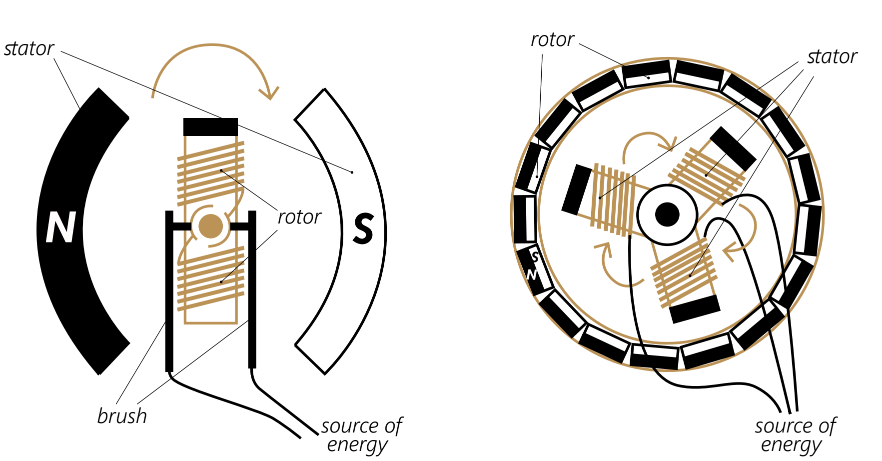


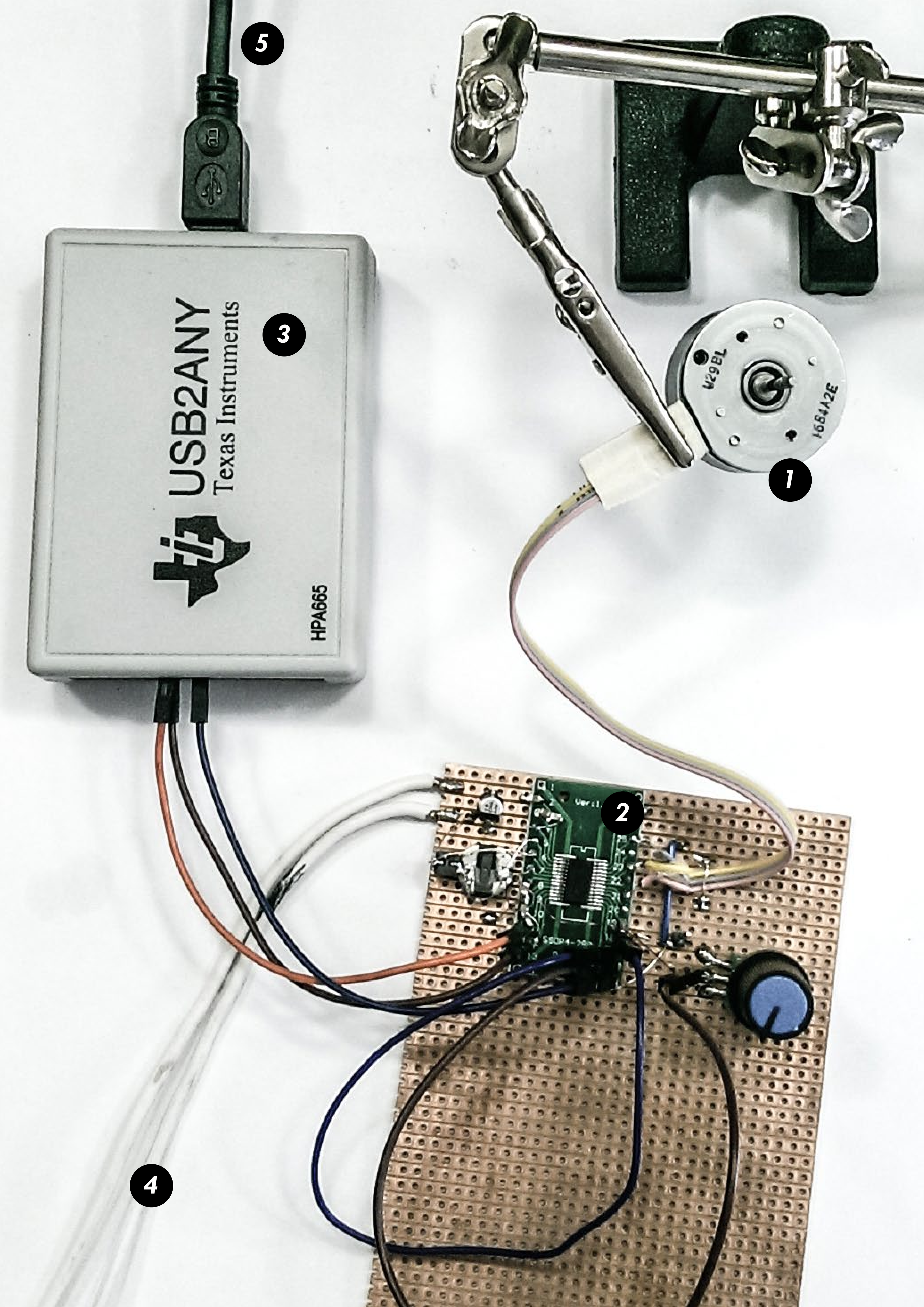
diagram SP13 **"brushed&braschless motor"**

braschless motor M29BL

CONCLUSION

The brushless motors are the right choice for the string-shooter design. During the experiment, it became clear that the diameter of "motor wheels" is too small to get the necessary speed for the string to be able to move. Obviously, the second layer of cover, which serves as a tire is needed. By the experiment, a manual back EMF motor driver was used. For the final tool, it needs to be replaced by one with a possibility of digital control.

photos © Tetyana Vovk, 2018 "ARCOUSTICON"


5
USB2ANY
Texas Instruments
HPA665
3
1
2
4

SPACE

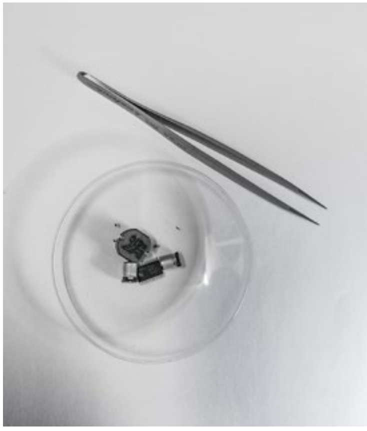
2. LAYER

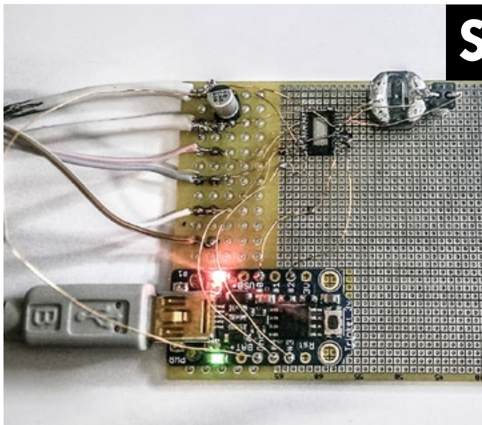
SP

STRING-SHOOTER

EXPERIMENT SP10
microcontroller connection and programing

1. ***BL electric motor (M29BL)***
2. ***Microcontroller DRV10987 12-to 24-V Three-Phase, sencorless BLDC motor driver***
3. ***Interface Adapter USB2ANY by Texas Instruments***
   "The USB2ANY is a small dongle intended to allow a computer to control an electronic evaluation module (EVM) via a USB connection. These EVMs cannot normally connect directly to the computer because of their specialized interfaces, which are typically supported on commercial computers" USB2ANY, Description, Texas Instruments 2018
4. ***energy source (12-to 24-V)***
5. ***software***





SP10

Application schematic DRV10987

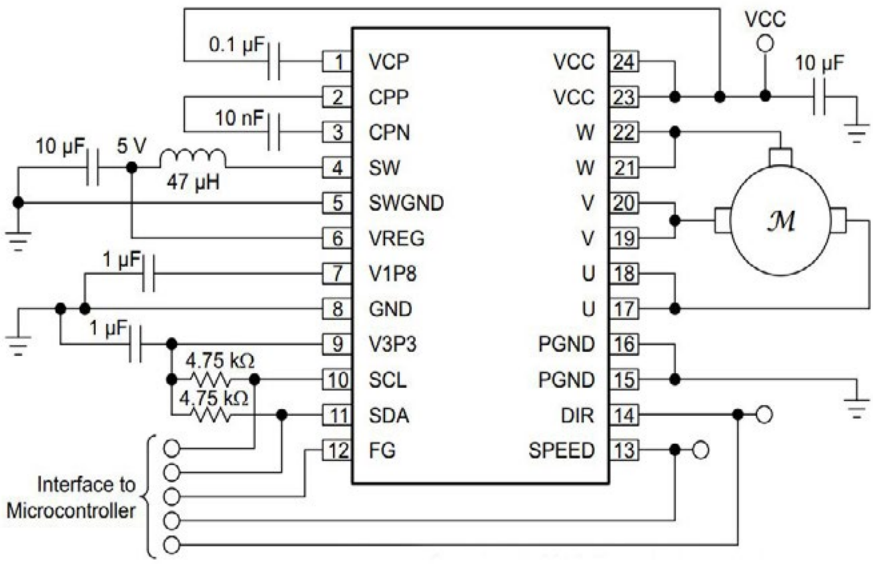


diagram SP14 by Texas Instruments Incorporated, 2017

photos © Tetyana Vovk, 2018 "ARCOUSTICON"


3
3

SPACE

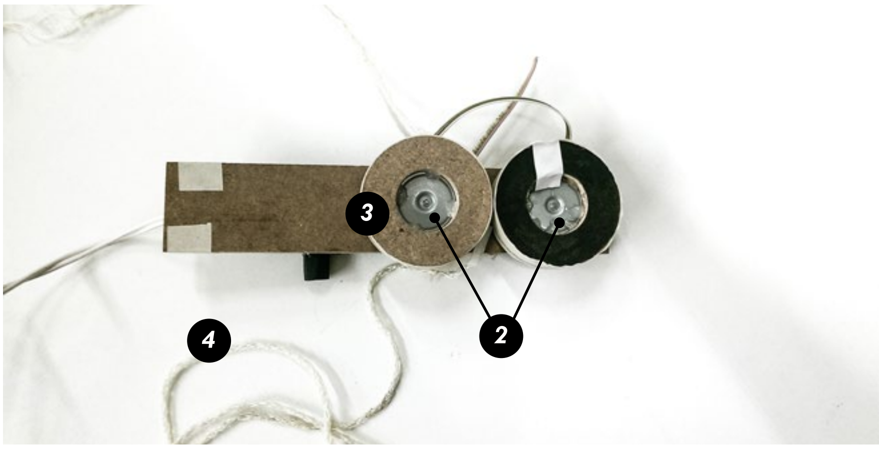
2. LAYER

STRING-SHOOTER

EXPERIMENT SP11

SP

SP11



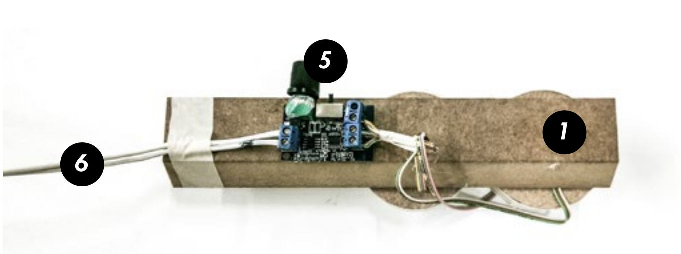
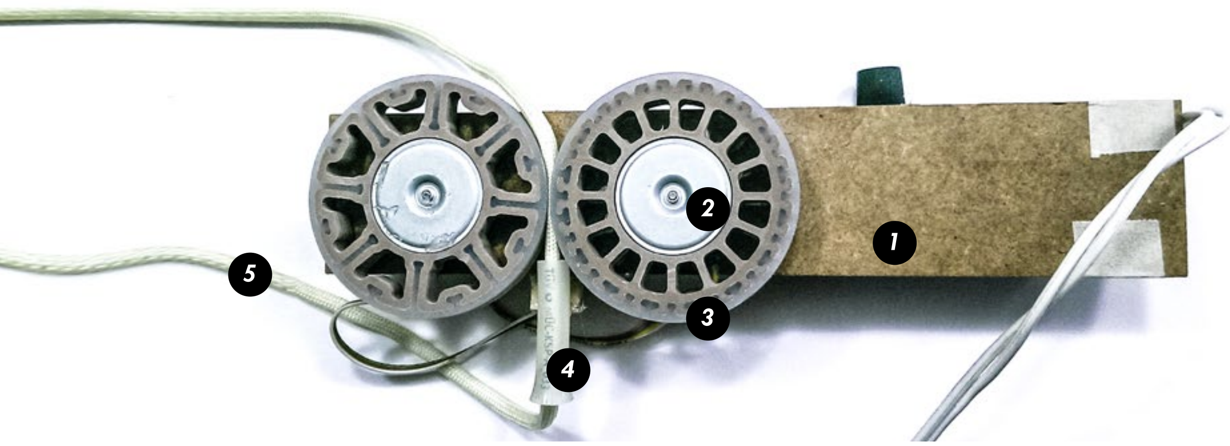


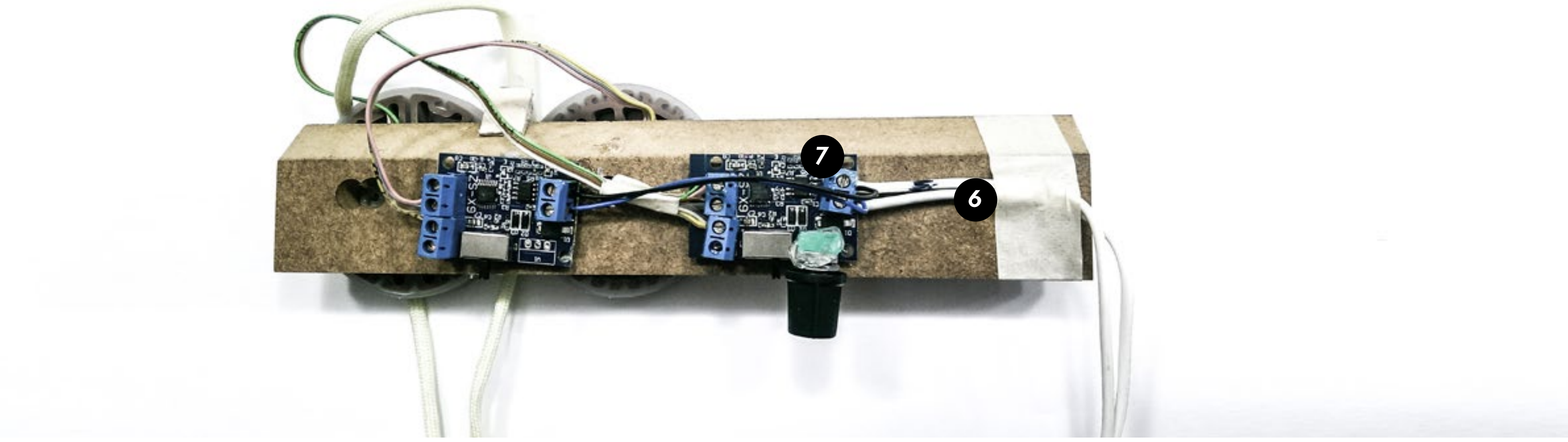
photo SP34 ***burned track***

1. ***base plate***
2. ***BL electric motor (M29BL)***
3. ***wheels (of fiberboard wood)***
4. ***string***
5. ***manual BLDC motor driver***
6. ***energy source (12-to 24-V)***

CONCLUSION

In this experiment, a fiberboard wheel is superimposed on a motor to make its diameter bigger. At the time the manual controller provides the control of motors. By this controlling type, and heavier weight (new wheels), the motors produce not enough power to get the string to rise up *(photo on the left side)*. Also, as we can see on the *photo SP34* the burned track created by a string during rotation stays on the wheel side. Both these problems need to be fixed.


5
2
1
3
4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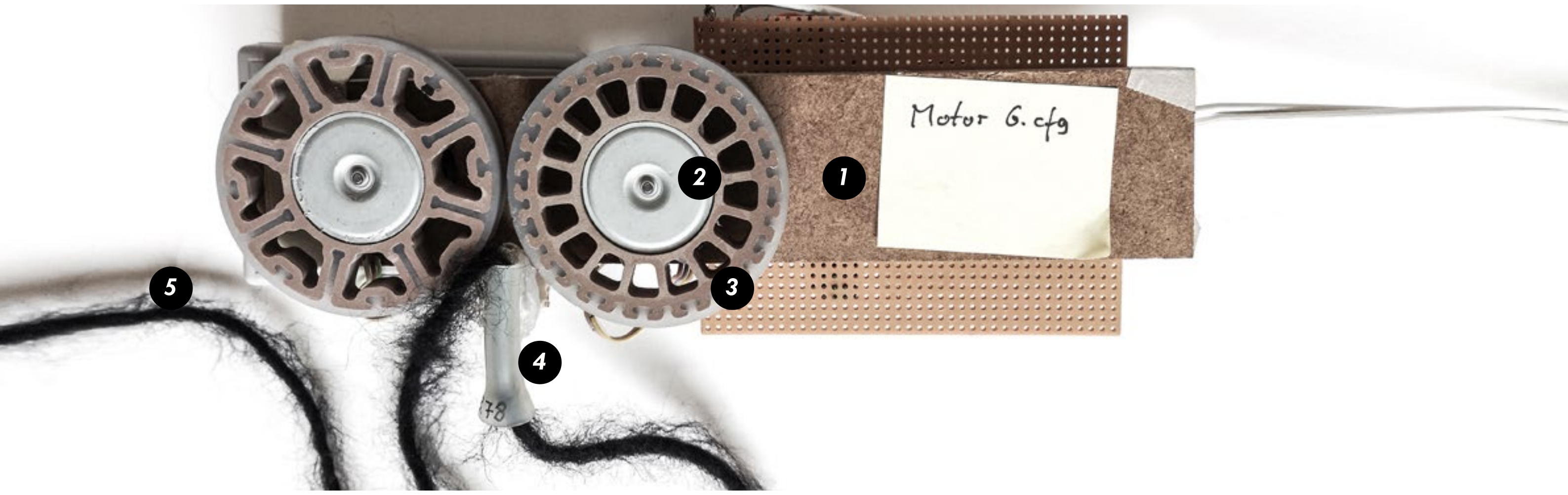
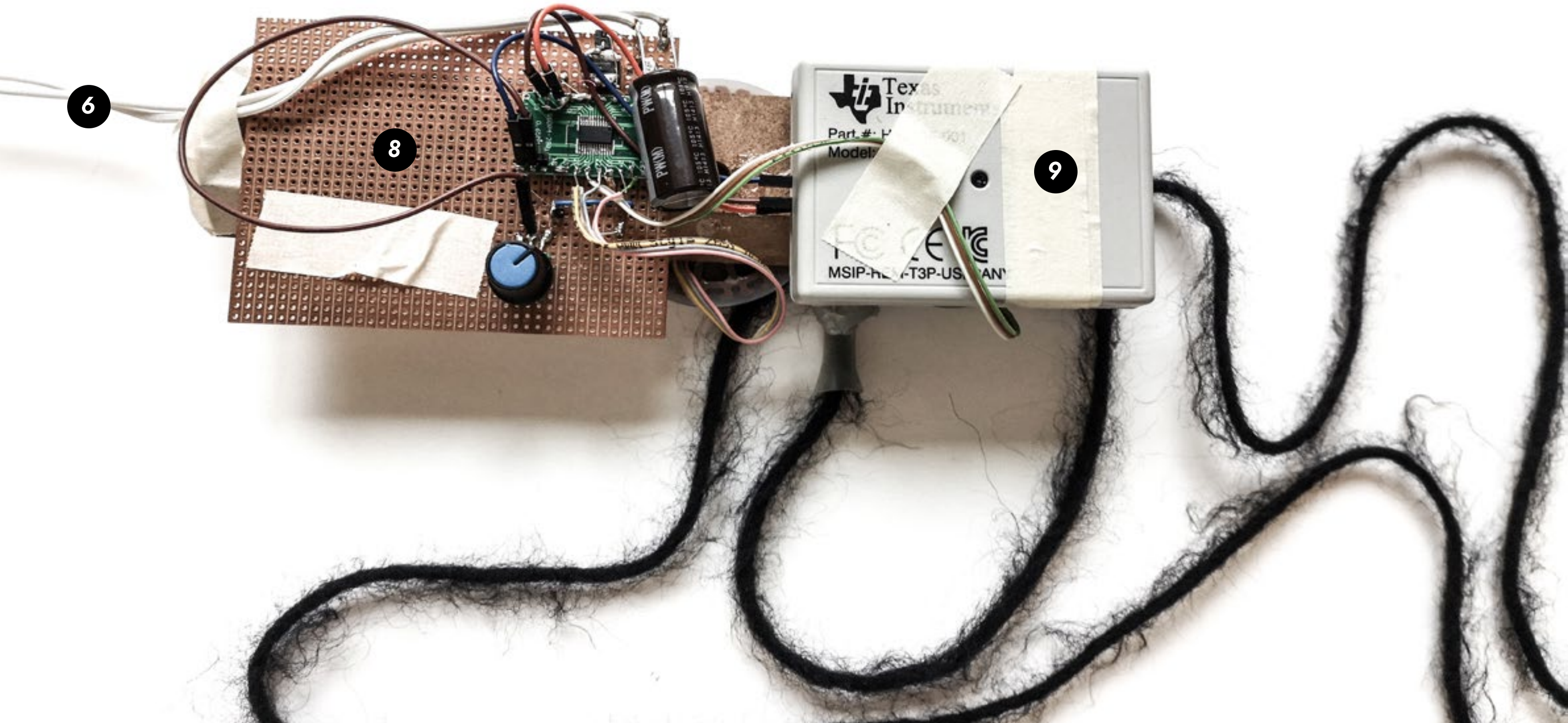
6


Motor 6.cfg
2
1
5
3
4


6
8
9

SP

MOVING TOOL

EXPERIMENT SP12

SP12

CONCLUSION

On the photos left showed the front and back side of the two next prototypes.

For these experiments, I made other wheels for the motors *(photo SP35)*. They consist of two layers: the rim-structure body, made from polyurethane (as lite but rigid material); and outer layer-tire, from silicone, as protection from burned tracks. The silicone layer also performs better by string pushing, because of its softness and stickiness.

Unfortunately, experiments have shown that with such a construction of the wheels, the silicone layer quickly separates from the polyurethane base. Using the speed you need for a string-shooter element to work properly, the centrifugal force is trying to pull out the silicone layer. This problem is shown on the *photo SP37 (photo was taken by help of stroboskop)*. This deformation is not expected in the final design, because it produces noise and interruptions during the string start.

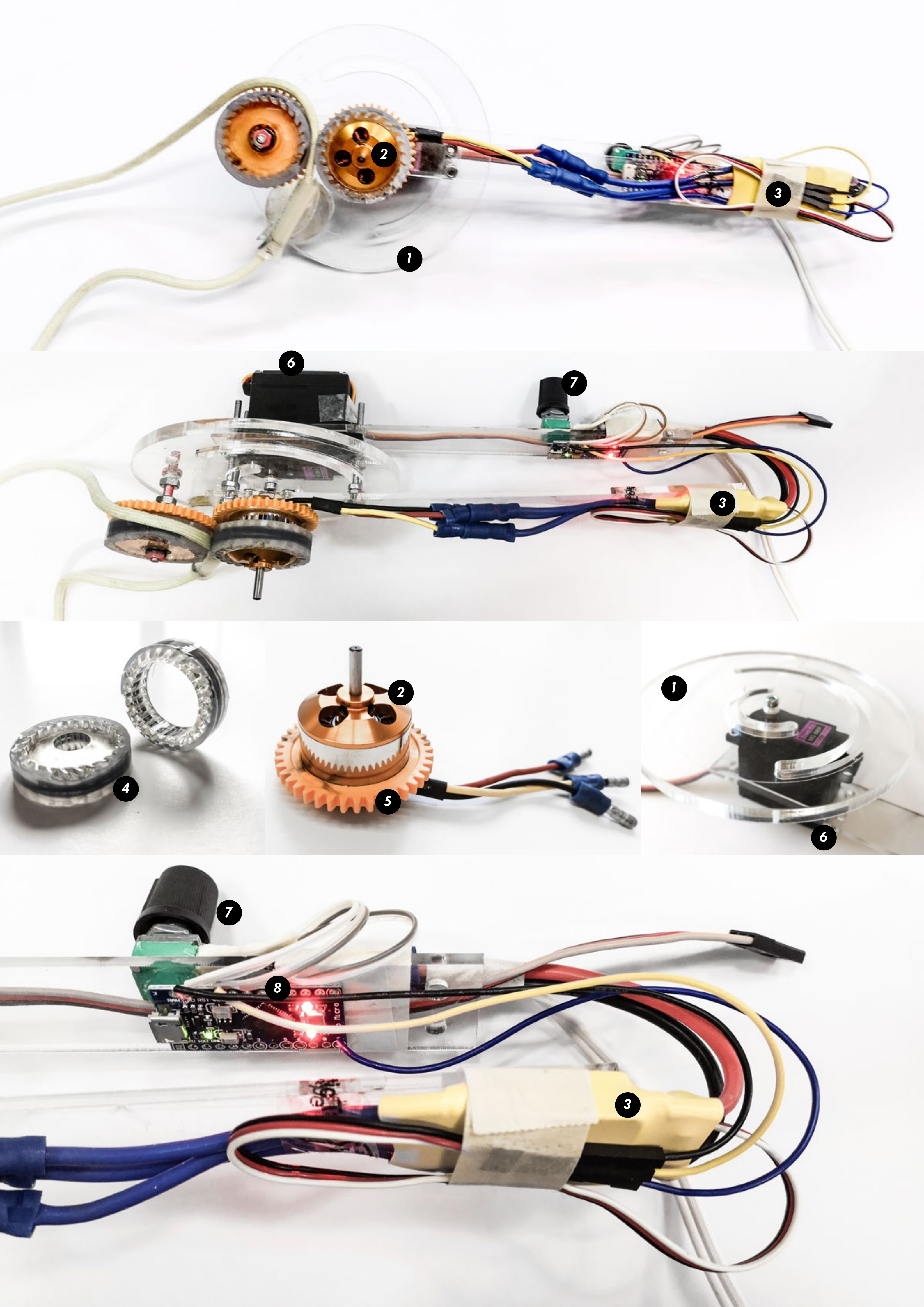
The main difference between prototypes in the photos on the left is their control system. Prototype above has a manual control system.

Tests have shown that, despite the possibility of changing some of the properties of the motor with the help of the digital control system, the power of the motors is still not enough for the full-fledged operation of the system. Also, the both wheel was rotating not synchronously which led to the destruction of the string (rope).

1. ***base plate***
2. ***BL electric motor (M29BL)***
3. ***wheels (rim and tire)***
4. ***string guide tube***
5. ***string***
6. ***energy source (12-to 24-V)***
7. ***BLDC motor driver***
8. ***sencorless BLDC motor driverDRV10987 12-to 24-V***
9. ***Interface Adapter USB2ANY by TI***

photo SP35

photo SP37


2
3
1
6
7
3
2
4
5
1
6
7
8
3

2. LAYER

MOVING TOOL

EXPERIMENT SP13

SP

SP13

The conclusions described above created the need for a new prototype *(photos on the left side)*. In this experiment, I tested not only the string-shooter system but also actuators *(servo motors)* for a movable hand.

REPLACED ELEMENTS:

1 ***base plate***
The bearing plate by the string-shooter system is now designed as a disk. On the photos, we can see that the disk has holes for connection of servo motor and wheel, and two long openings for connection with a structure of the movable hand.

2 ***BL electric motor A2212/10T 1400KV***
The motor was replaced by a more powerful one but at the same time bigger in a size. The second wheel in the system is rid of the motor. The motor is replaced by the axis with two ball bearings.

3 ***Microcontroller ESC-30 brushless speed controller***
A new type of digital controller needed for a motor control.

4 ***wheels (rim and tire)***
Via to a new size of the motor, the new wheels were made out of plexiglass. In the new design around the rim was wrapped a thread, for a better connection of silicone layer with its body.

NEW ELEMENTS:

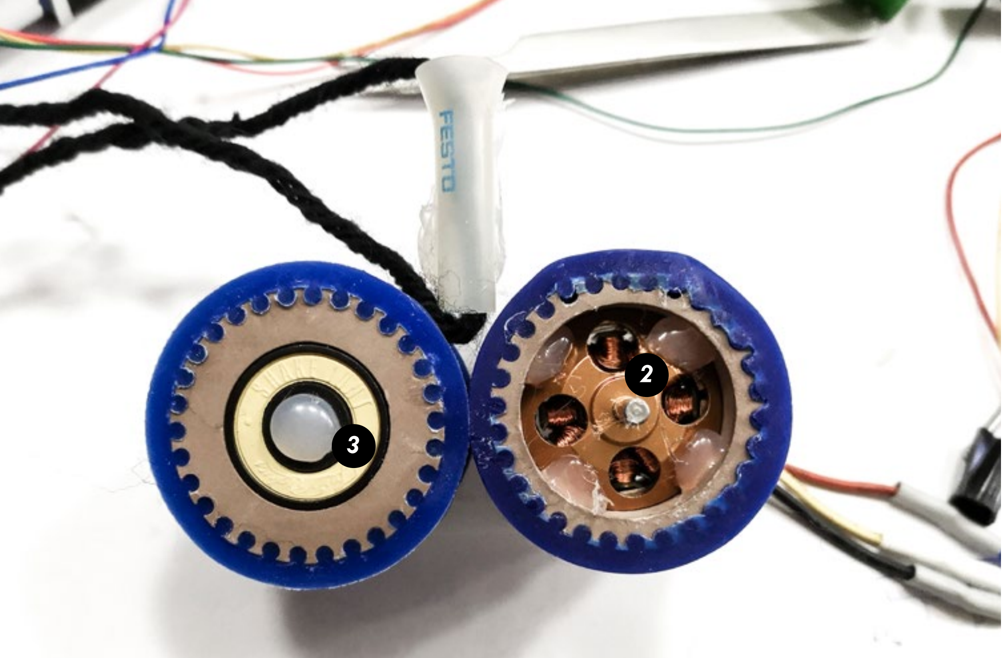
gear synchronization 5
Since there is no second engine in the new string-shooter system, there is a need for an element, able to transmit the inertia of the rotation between two wheels.

servo MG996R 6
The new type of motor as an actuator for a movable hand.

manual servo controller 7
It is necessary to control the servo movement.

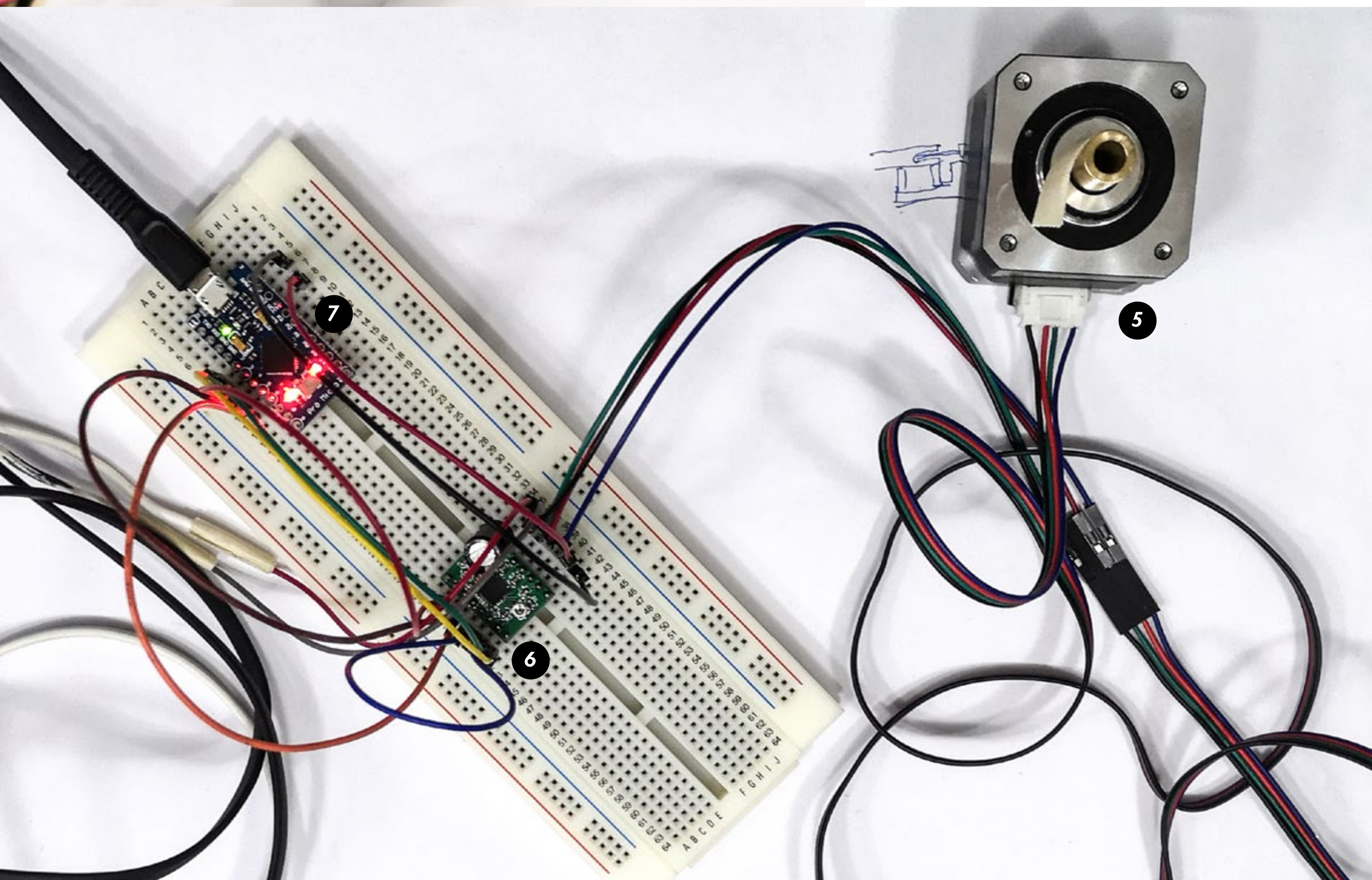
arduino pro micro (AT mega328) 8
microcontroller with an USB to take a controll of ESC-30 speed controller

photos © Tetyana Vovk, 2018 "ARCOUSTICON"


FESTO
2
3


SHAKE JUNT
1


4


7
5
6

SPACE
2. LAYER
MOVING TOOL
EXPERIMENT SP14

SP14

For this experiment, new wheels were also developed in two layers, polyurethane and silicone. The process of their manufacturing is described on the next page in more detail.

Also, the new bearing plate provides a connection between the string-shooter system and a movable hand. On the photos on the left, we can see how the two wheels are connected to this plate: motor with the first wheel; axis with a bearer as a movable core with another wheel. On the last photo a stepper motor is shown. Two stepper motors are implemented in the movable hand system as actuators for rotation in two axes.

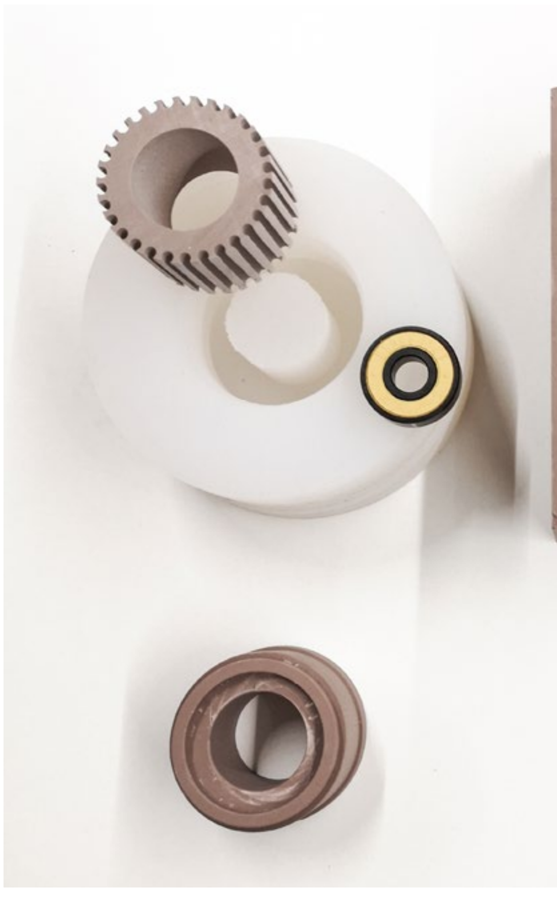
The control system of stepper motor includes micro stepper driver and microcontroller (in this experiment Arduino micro) to send a digital signal from a new position (rotation angle) and receive a data of a new position.

1. ***base plate***
2. ***BL electric motor A2212/10T 1400KV***
3. ***axis with two ball bearings*** bearing structure for a second wheel
4. ***wheels***
5. ***stepper motor*** actuator for movable hand
6. ***A4988*** microstepping drivers for stepper motors
7. ***microcontroller*** arduino micro


photo SP38


photo SP39


photo SP40

photo SP41


WHEELS PRODUCTION

To create the wheels as one monolithic structure of two layers, I needed to pour silicone in the way that it directly touches the body of the first bearing layer of the wheel.

The idea is that the fixing silicone is glued to the bearing layer creating a solid structure.

On the following photos production process is described step by step.

First, a 3D model of all parts was created. Then, using CNC machine the bearing layer of the wheels (rim) was produced in two different sizes (because of different diameter). In a same way was produced the inverted form for main silicone form *(photo SP38,39)*.

After that, the silicone was poured into the inverted form *(photo SP40)*. As a result, I got a silicone mold, flexible and soft *(photo SP41)*.

Now, inside the silicone form comes rims of the wheel, and silicone can be poured one more time, for the final result *(photoSP42)*. The result is shown in the photos on the previous page.

photo SP42

photos © Tetyana Vovk, 2018 "ARCOUSTICON"

SP

photo SP43

photo SP44

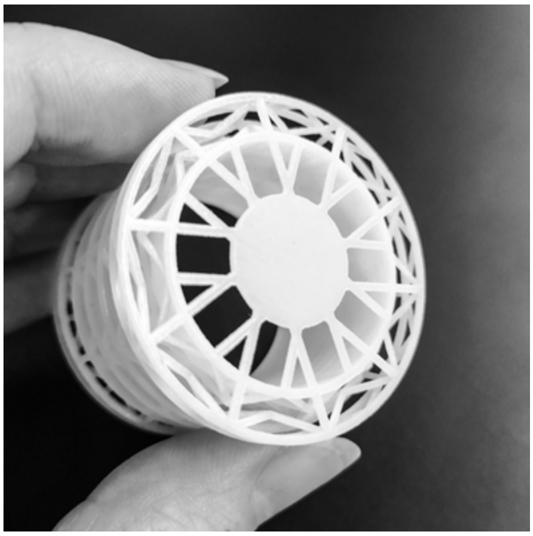
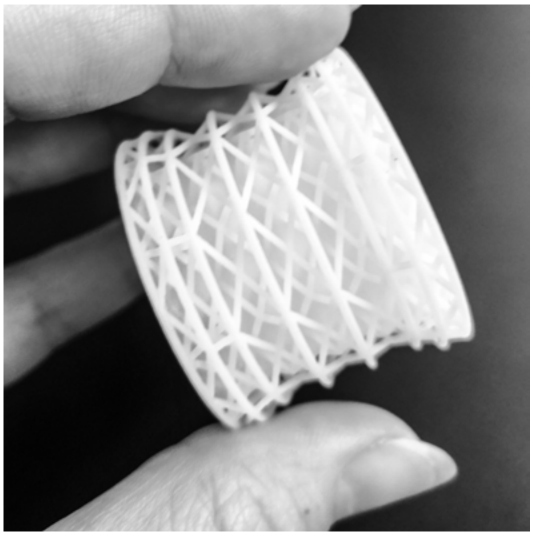


photo SP45



WHEELS EVOLUTION

Tests have shown that, unfortunately, with such a geometry of the bearing layer of the wheel as described above, at high turning speeds the silicone begins to lag behind.

That result is not permissible since the use of such wheel leads to the generation of noise and obstacles in the motion of the string.

To fix this issue the decision was made to change the geometry of the bearing layer in a way that it created a "sponge" structure. Through many openings, the silicone could flow inside bearing body and glued *(photo SP43-45)*.

The structure was produced using 3D printing. The thickness of bridges is only 0,8mm.

The following steps of the production process stay the same as described on the previous page *(photos on the right side)*.

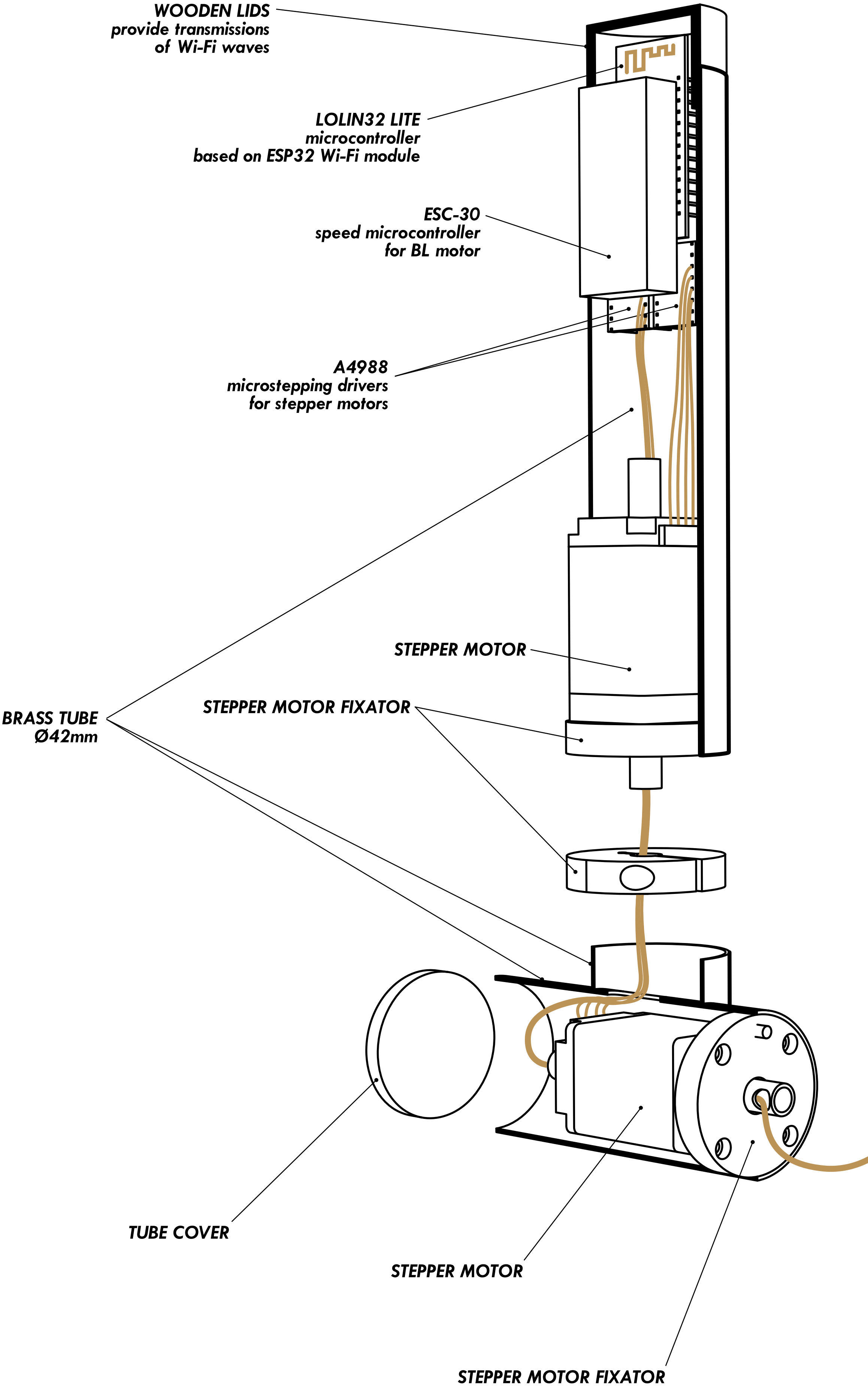
The created wheel was tested and as a conclusion, has to be used in the final design. During rotation, the silicone layer stays glued to the bearing structure. Also due to the thickening of both ends, the transmission of inertia of the movement is carried out
Unlike the gear system, this approach provides synchronous movement of the wheels without producing noise and without destroying

photos © Tetyana Vovk, 2018 "ARCOUSTICON"

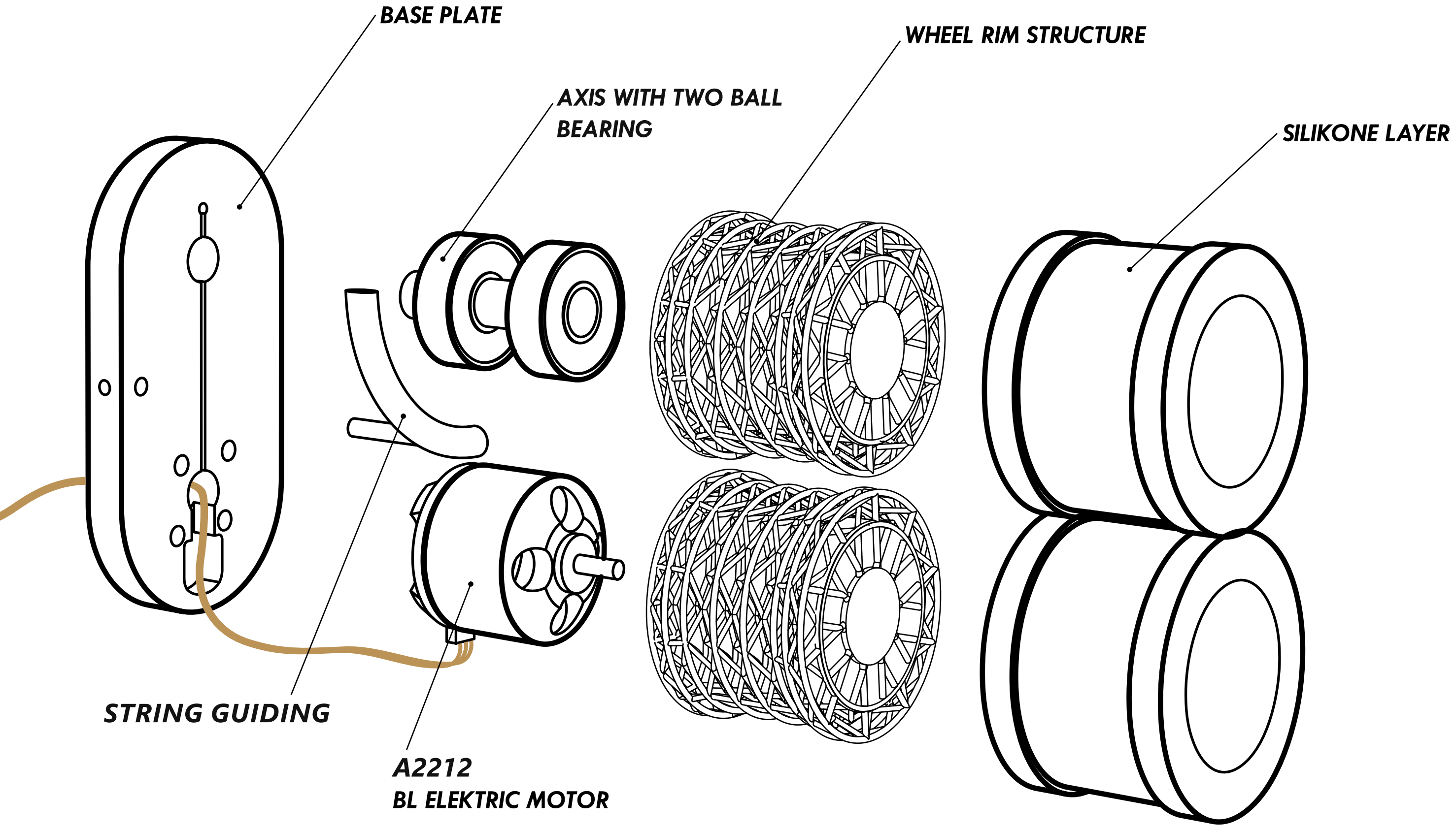
MOVING TOOL

DETAILS

DRAWING SP17



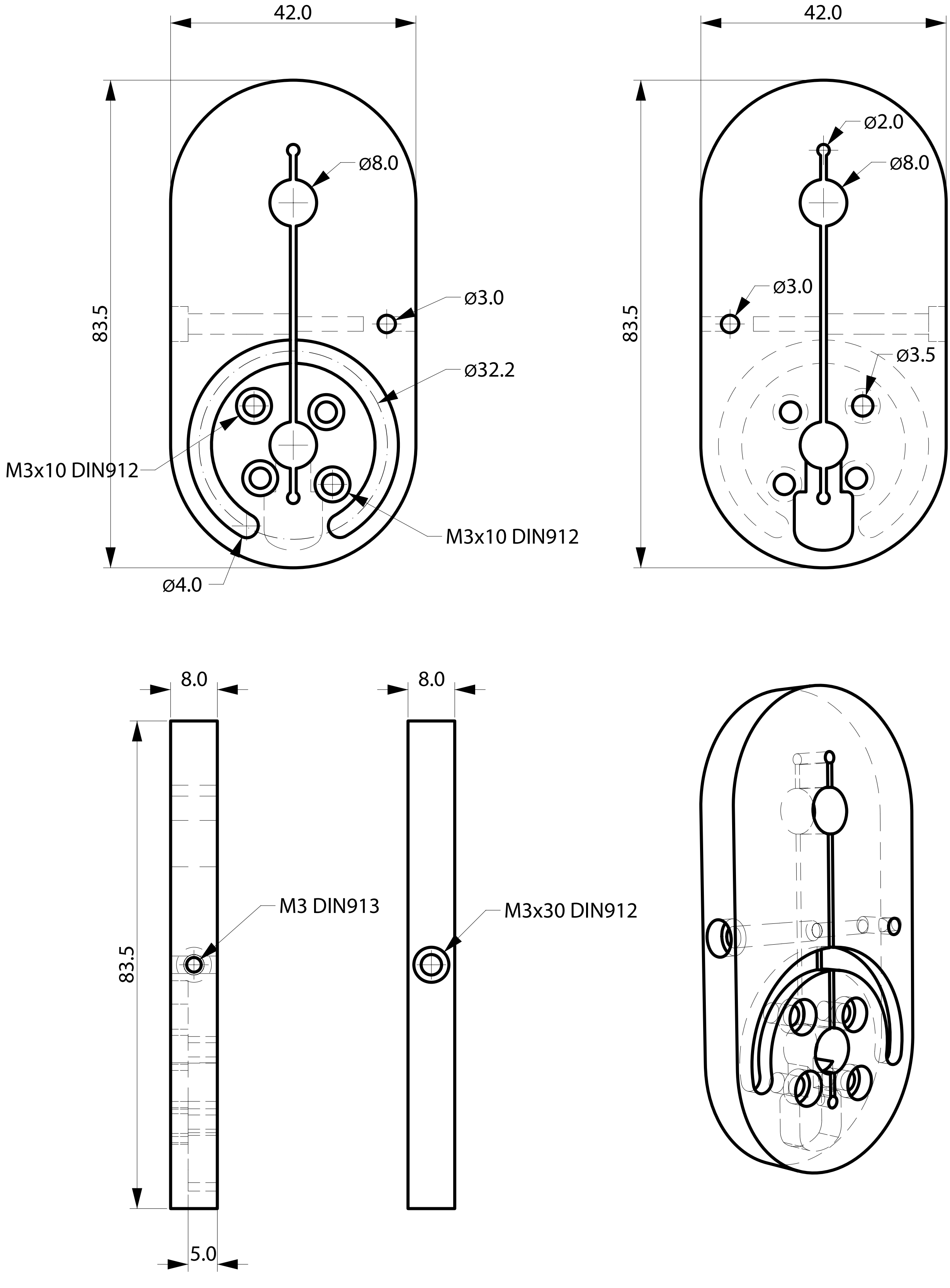
STRING-SHOTTER SYSTEM



MOVING TOOL

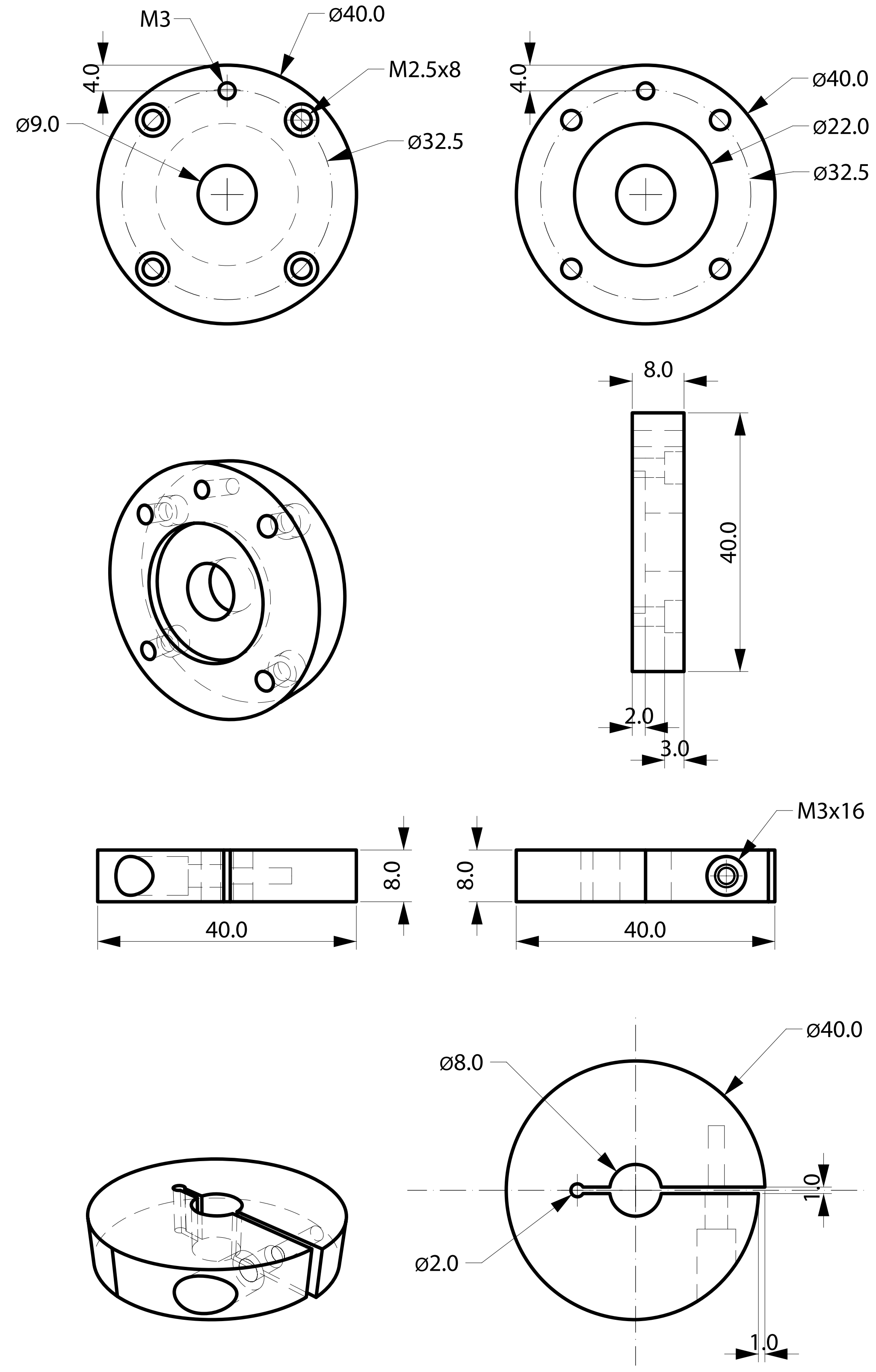
DETAILS, DRAWING SP18
M=1:1

BASE PLATE



DETAILS, DRAWING SP19
M=1:1

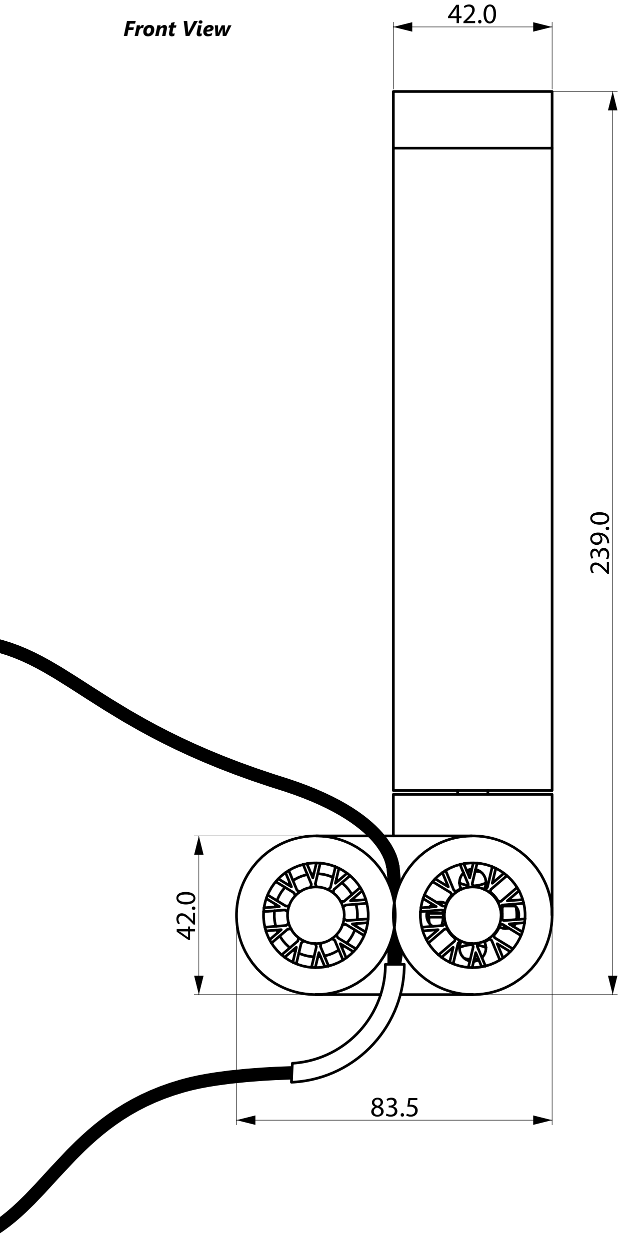
STEPPER MOTOR FIXATOR



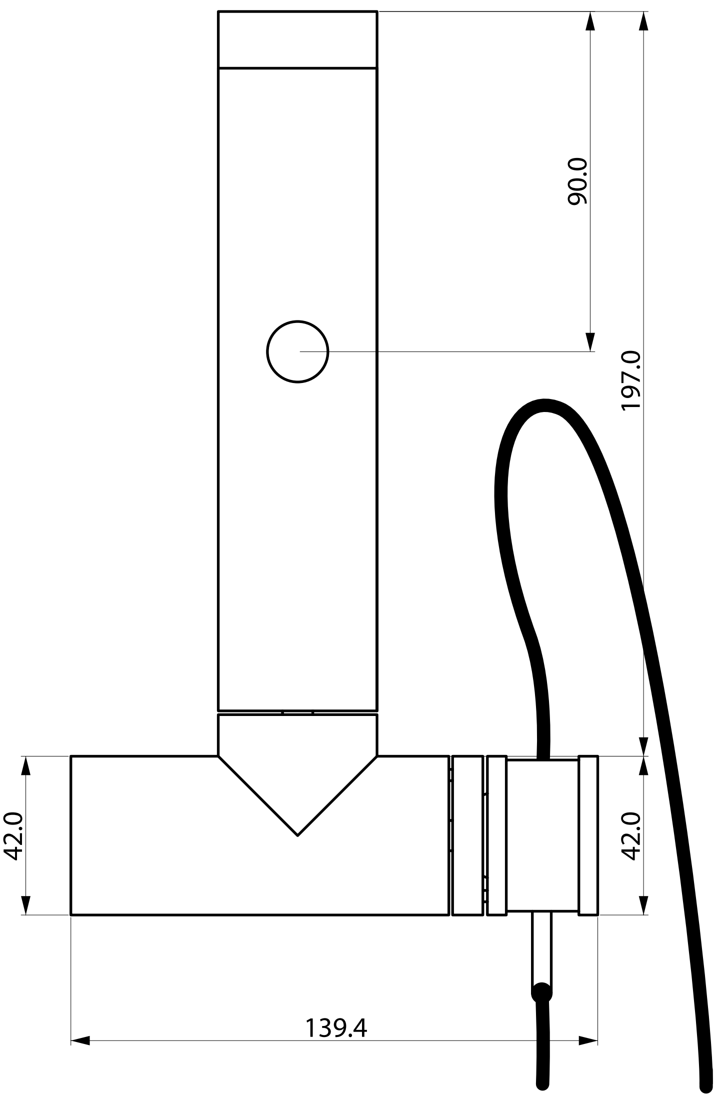
MOVING TOOL

FRONT VIEW, SIDE VIEW, TOP VIEW
DRAWING SP20
M=1:2

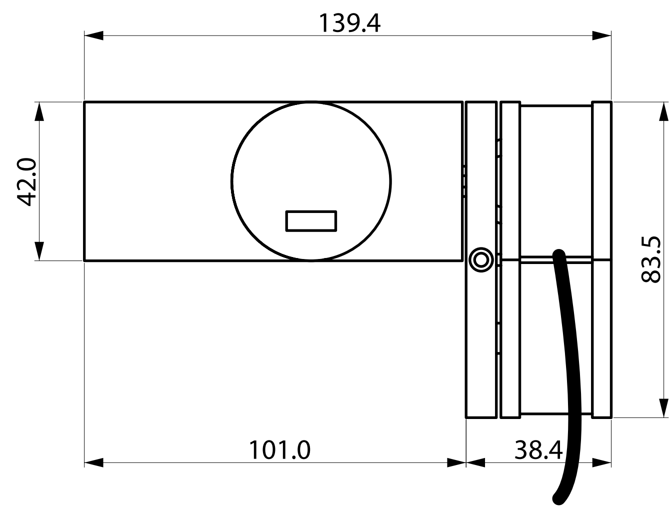
Front View



Side View

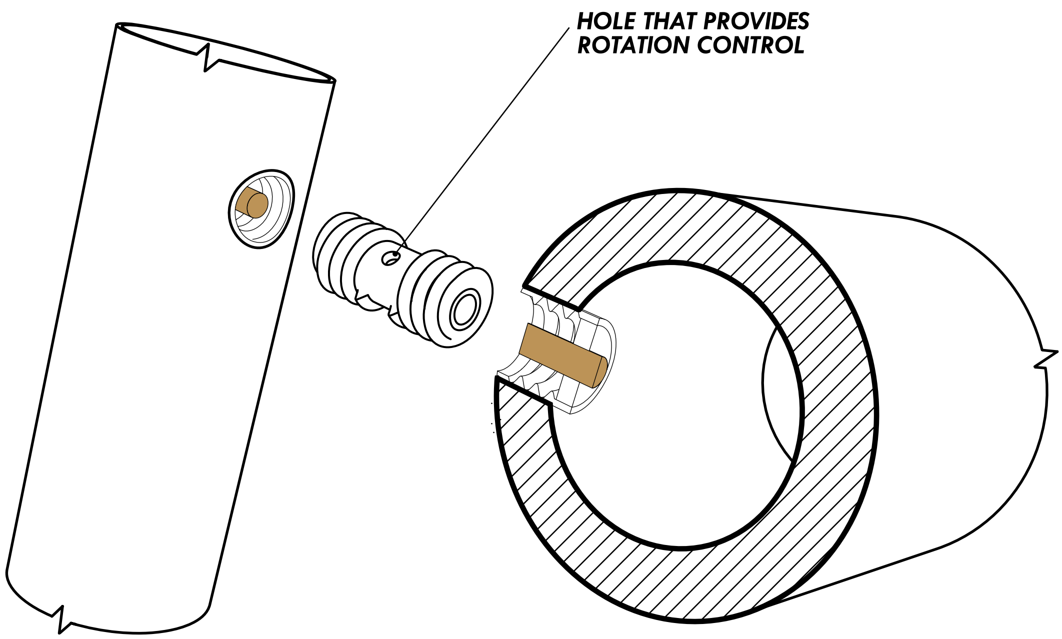


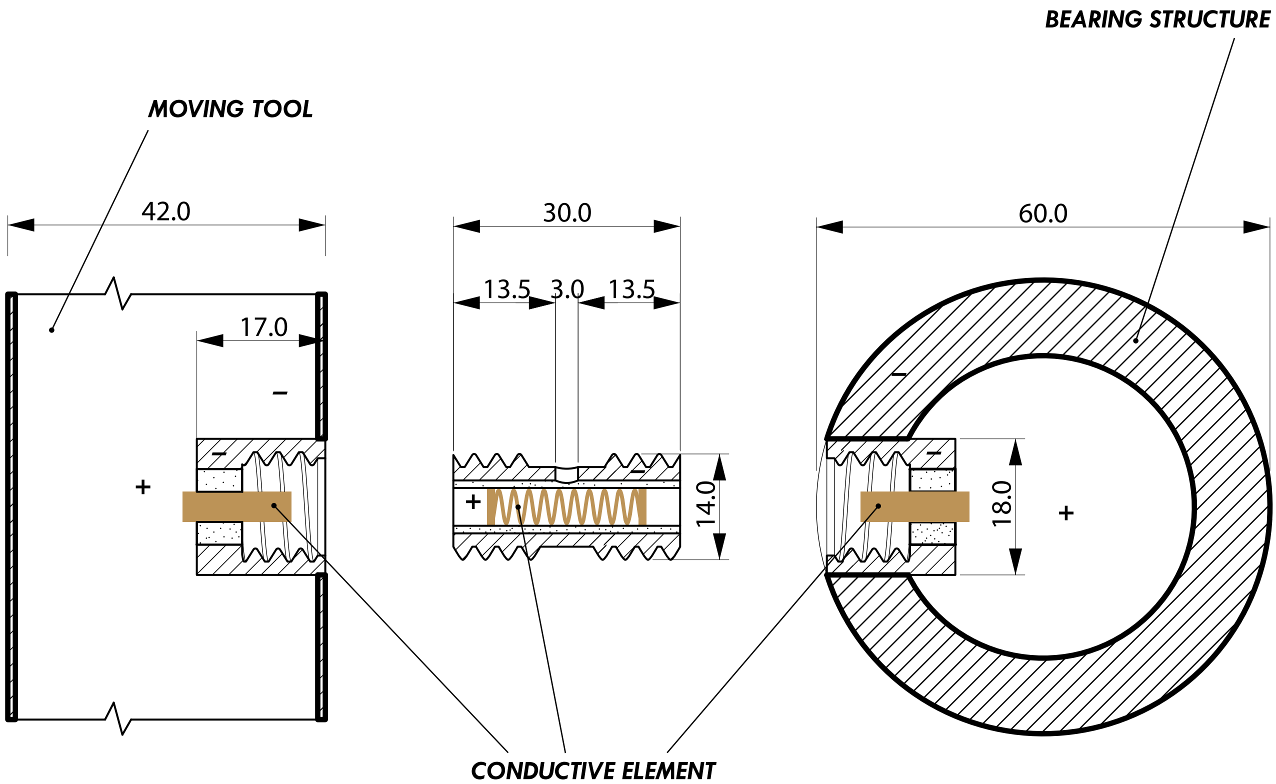
Top View

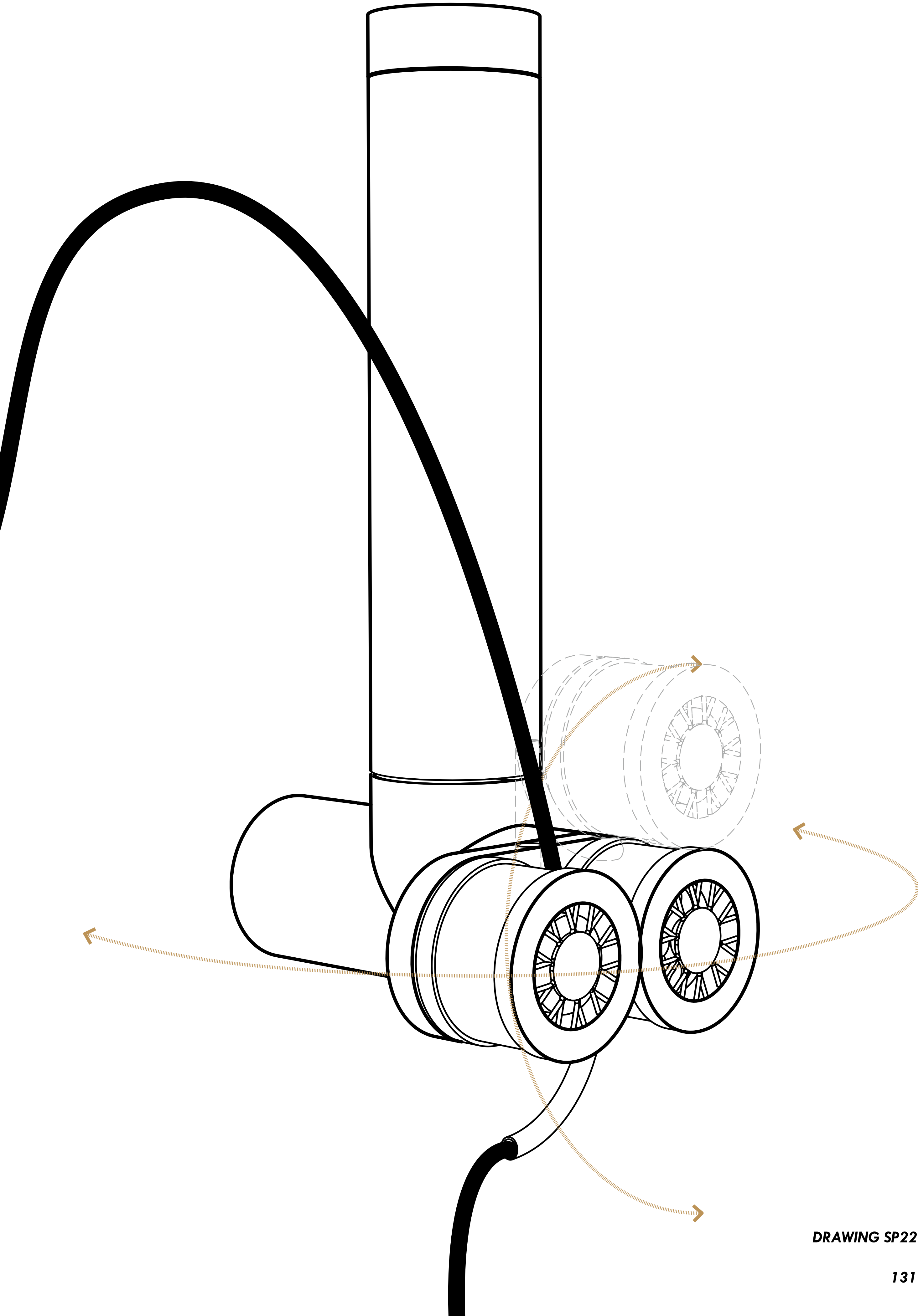


MOVING TOOL

DETAIL, DRAWING SP21
TYPICAL JOIN SYSTEM BETWEEN BEARING STRUCTURE AND MOVING TOOL
M=1:1



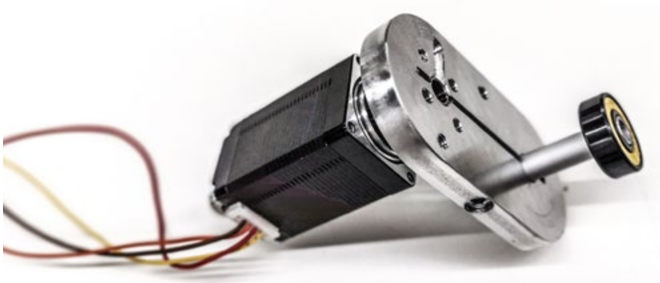


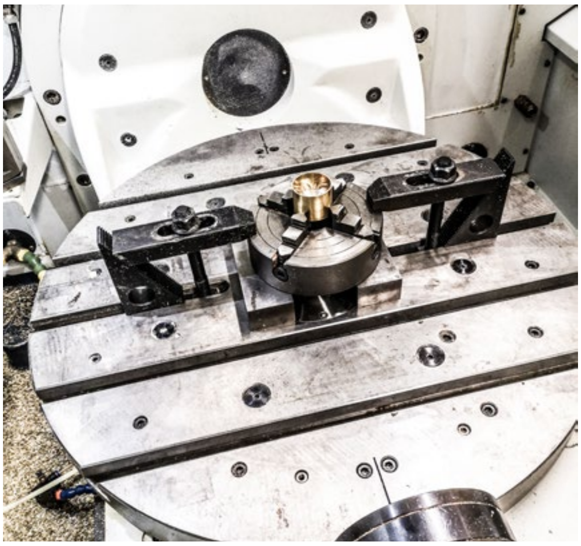


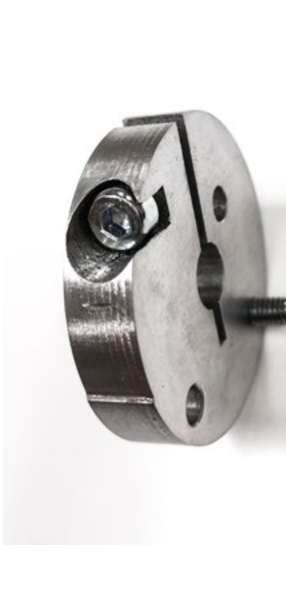
DRAWING SP22

MOVING TOOL

PROTOTYPE PRODUCTION
photos © Tetyana Vovk, 2018 "ARCOUSTICON"

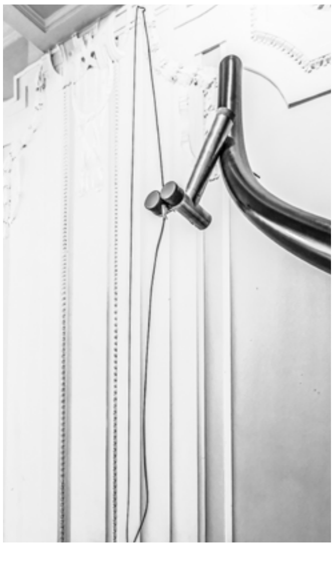


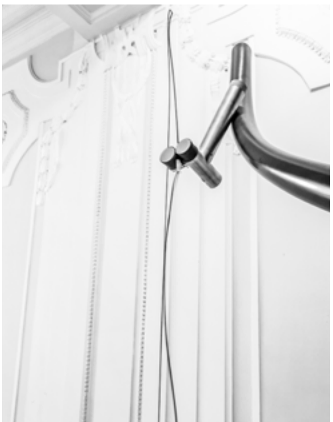




MOVING TOOL

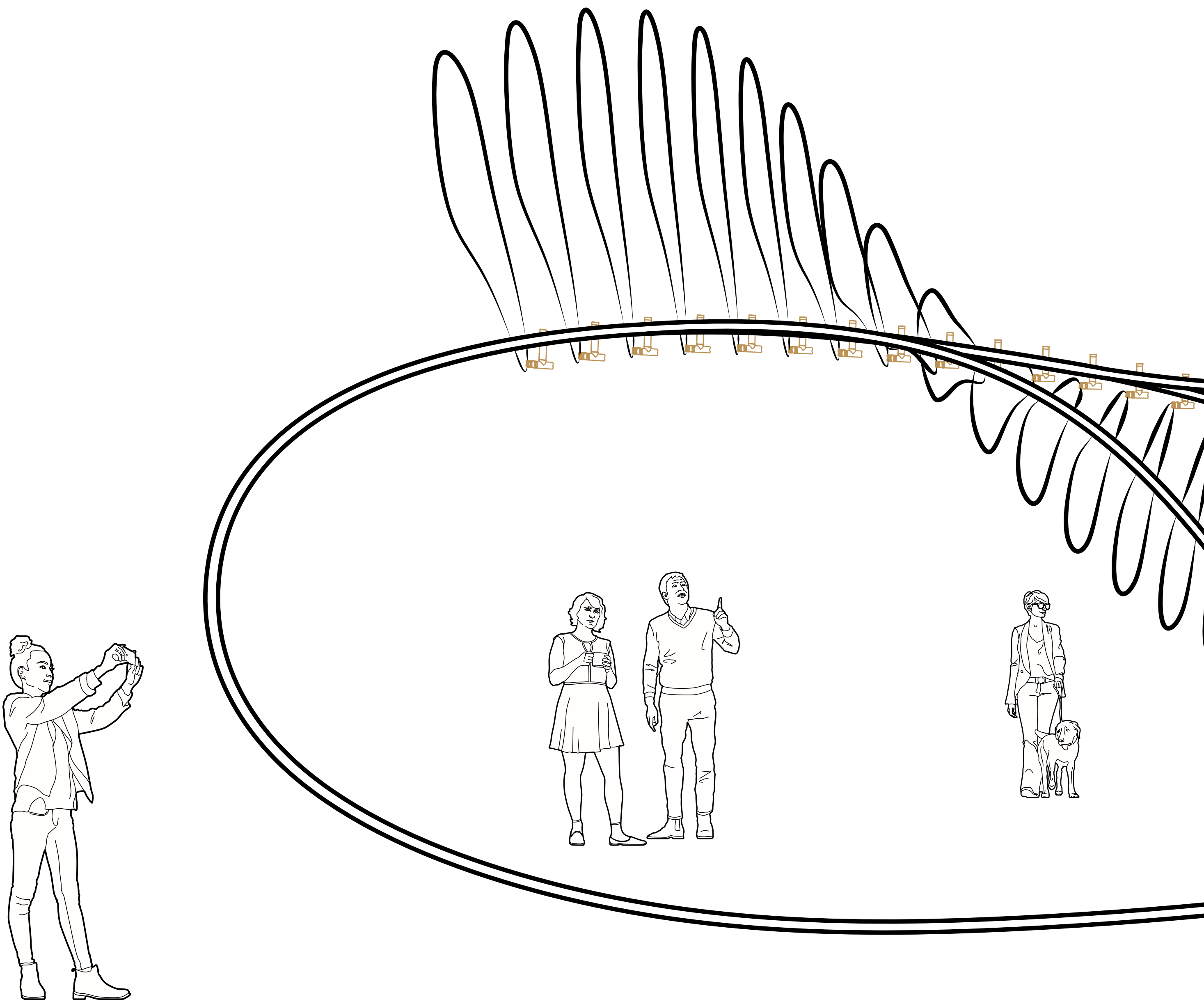
PROTOTYPE PRODUCTION
photos © Tetyana Vovk, 2018 "ARCOUSTICON"



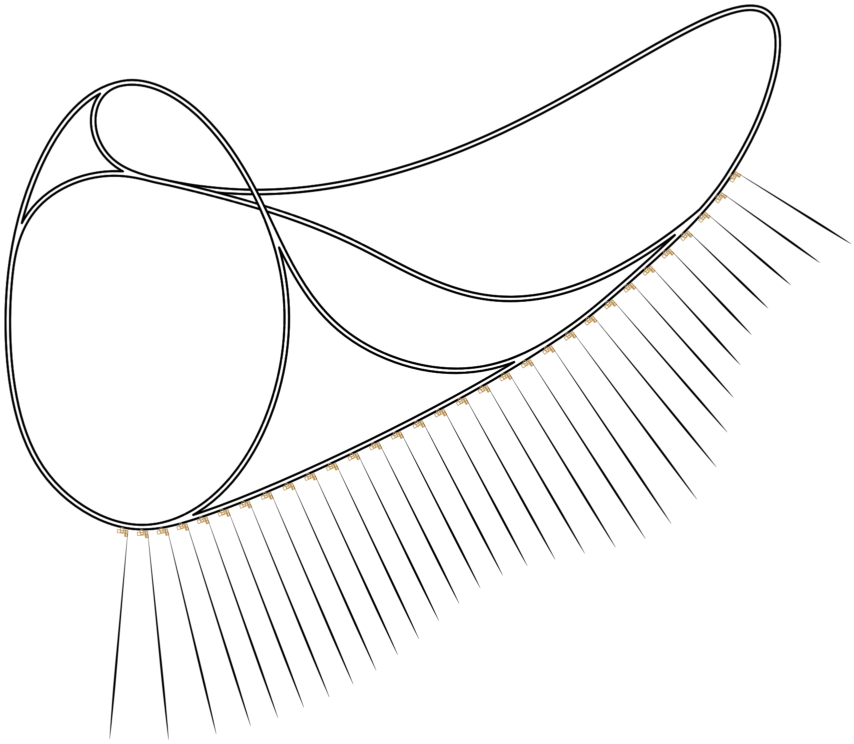


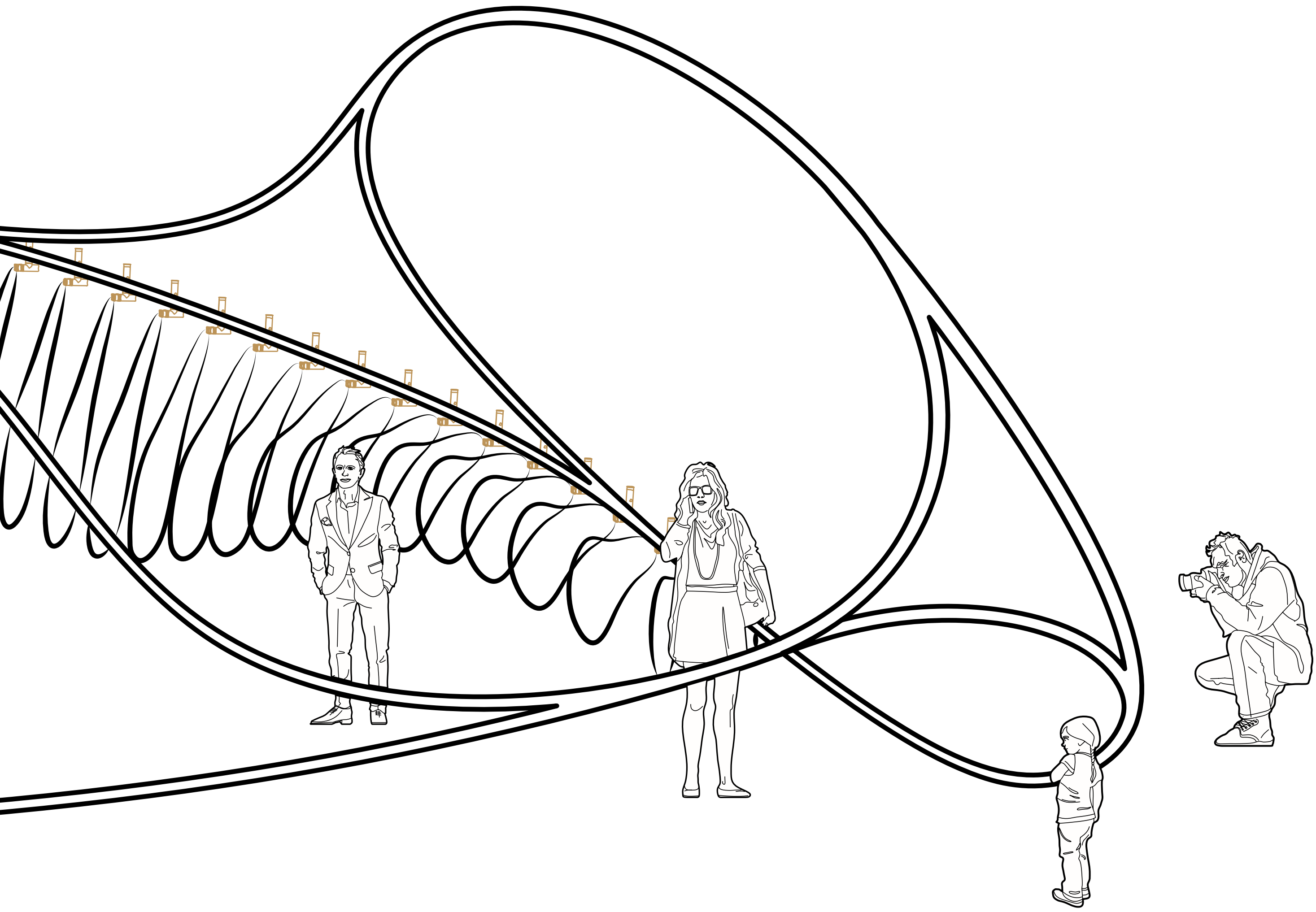
1.LAYER
BEARING STRUCTURE
+
2.LAYER
MOVING TOOLS
PERSPECTIVE VIEW

DRAWING SP23



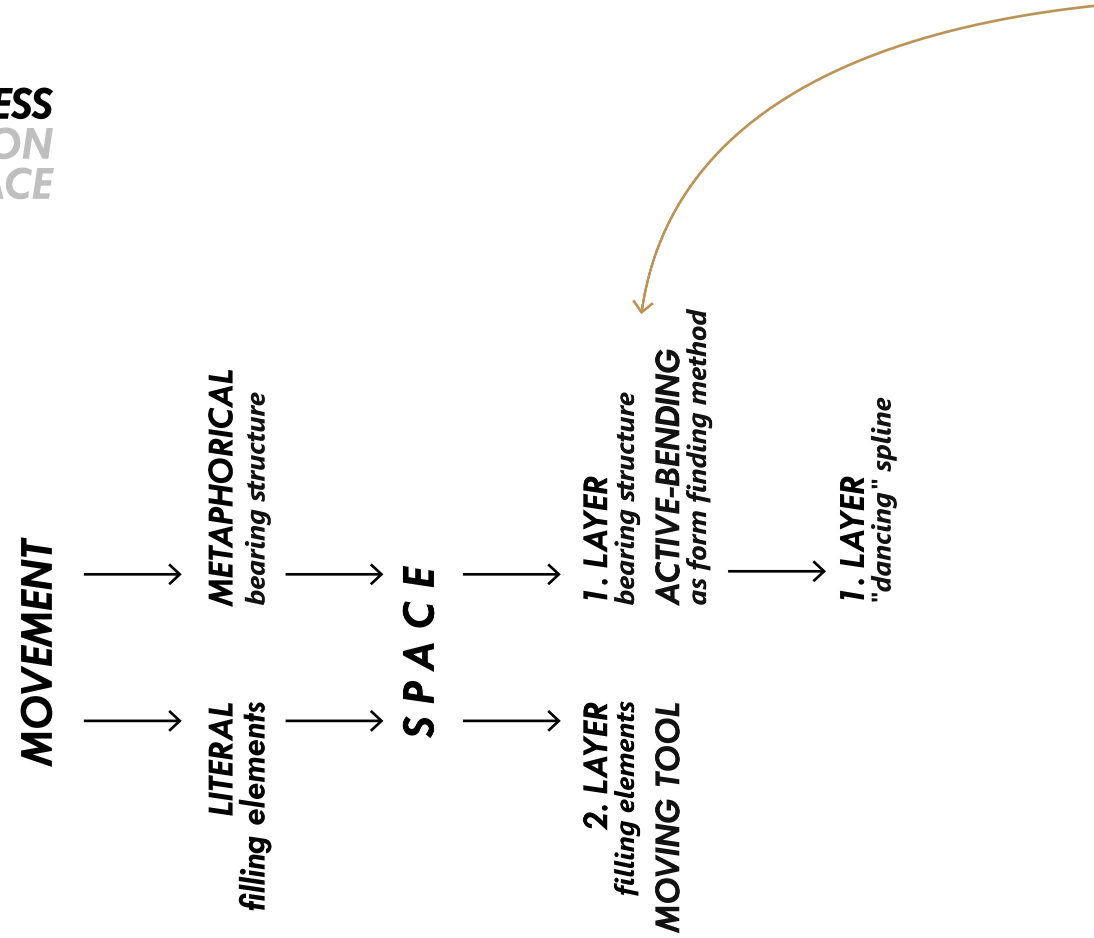
drawing SP24
***Top View,** M=1:100*





SP

DESIGN PROCESS
CONCLUSION
SECTION SPACE



In section ***SPACE*** was separately discussed and designed two layers of Arcusticon structure: 1. Layer- bearing structure and 2. Layer- filling elements.

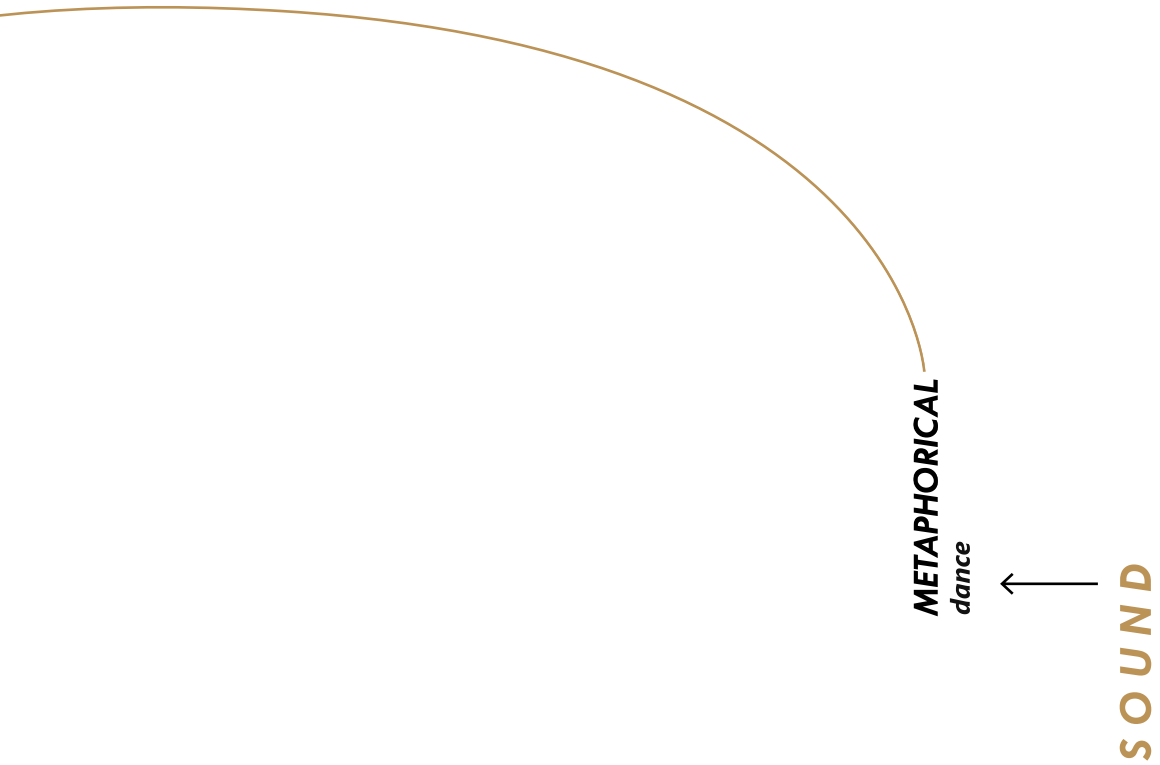
For the first layer of the structure was chosen the metaphorical approach of music (dance) representation in architecture. The form itself was designed by using an active-bending method as a form-finding method. This method has a metaphorical connection with music not only in the pavilion’s form but in the way of its creation.

The real tension in the structural elements corresponds with the physical and emotional tension of a dancer creating motion through space.

After static calculation were defined material and final size of the structure. The main function of the 1. structural Layer is to be a base for all another layer of the Arcousticon pavilion.

The 2. Layer is represented by moving tools as main filling elements capable of space creation during movement. Basically, they have two degrees of freedom (can be rotated along two axis), and three actuators that needed to be controlled.

All phases of the design process are described step by step in this sec-



tion. The final design is based on empirical experiments, also described above.

For the next steps in the design process is necessary to explore a musical section, to find the right tools for the 3. Layer of the structure (musical tools). The type of this tools can determine the main rules of interconnection between music and space-creating elements (moving tools), being the main source of data (determination of rotation) for actuators in the moving tools.

The design process of the section SPACE is explained in the diagram above. Till now music was implemented just metaphorically in the pavilion design by 1. structural Layer.

The next question is how can we use musical resources to implement it literally in the ***ARCOUSTICON*** design?

SOUND

sO

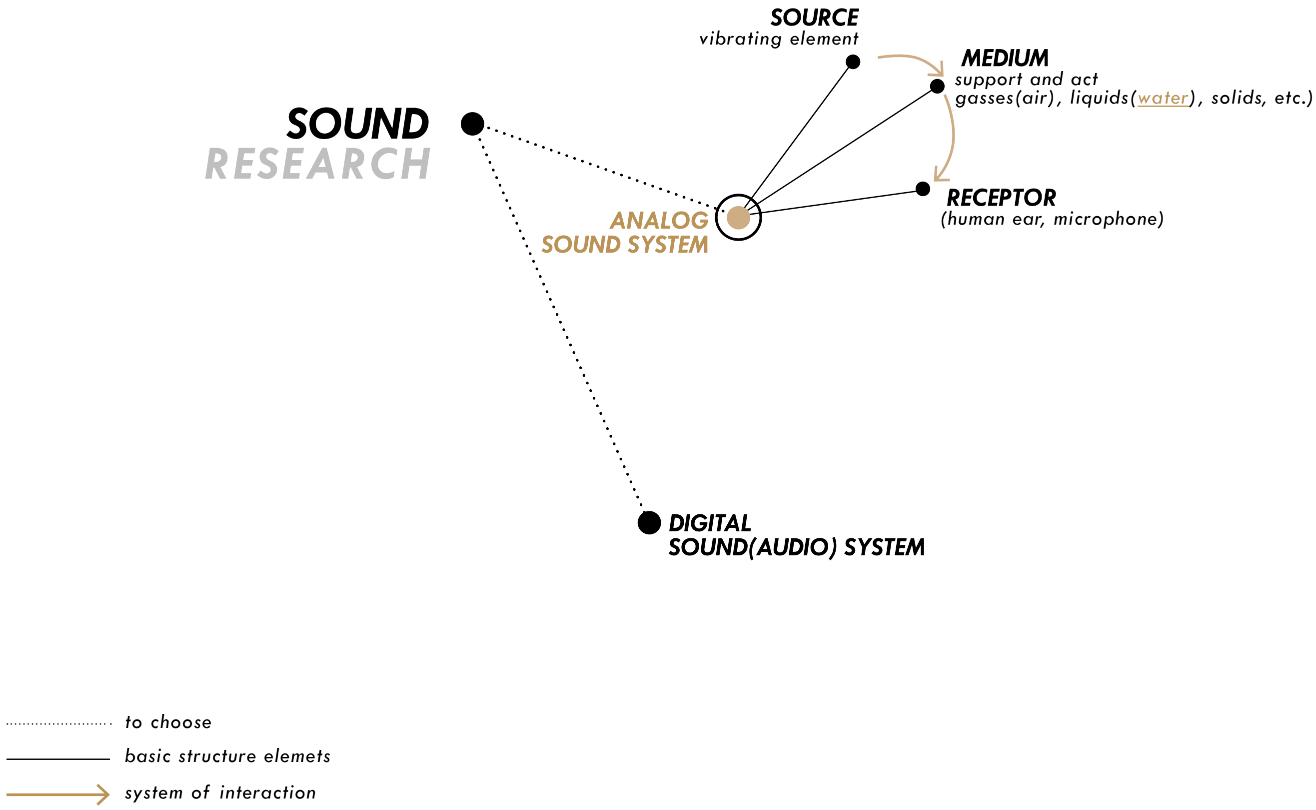


diagram S1 ***"sound systems"***

In this paper, ***music*** in architecture is considered as a combination of two components: the ***sound*** itself and the ***rules*** of its creation and structurization. This section focuses on the theme ***sound***. On *diagram S1* we can see two different ***systems of sound generation: analog***, and ***digital***. To understand the difference between them let's take a closer look at the sound in the usual (analog) form.

ANALOG SOUND SYSTEM

This system consists of a ***source*** (instrument), ***medium*** (air) and ***receptor*** (listener)[1] *diagram S1*. Physically sound is the oscillatory motion of particles of an elastic medium that propagates in the form of waves in gas, liquid, or solid. In the narrow sense, under the sound, are understood oscillations that are perceived by the sensory system of animals and humans[2].

1 Roederer, Juan G. (2008 [1973]), 4th Edition: Physics and Psychophysics of Music, The Intervening Physical Systems, p.1

2 "Humans can only hear sound waves as distinct pitches when the frequency lies between about 20 Hz and 20 kHz. Sound above 20 kHz is ultrasound and is not perceptible by humans. Sound waves below 20 Hz are known as infrasound. Different animal species have varying hearing ranges." Wikipedia (last edited 2018): Sound, https://en.wikipedia.org/wiki/Sound, last view: 28.10.2018

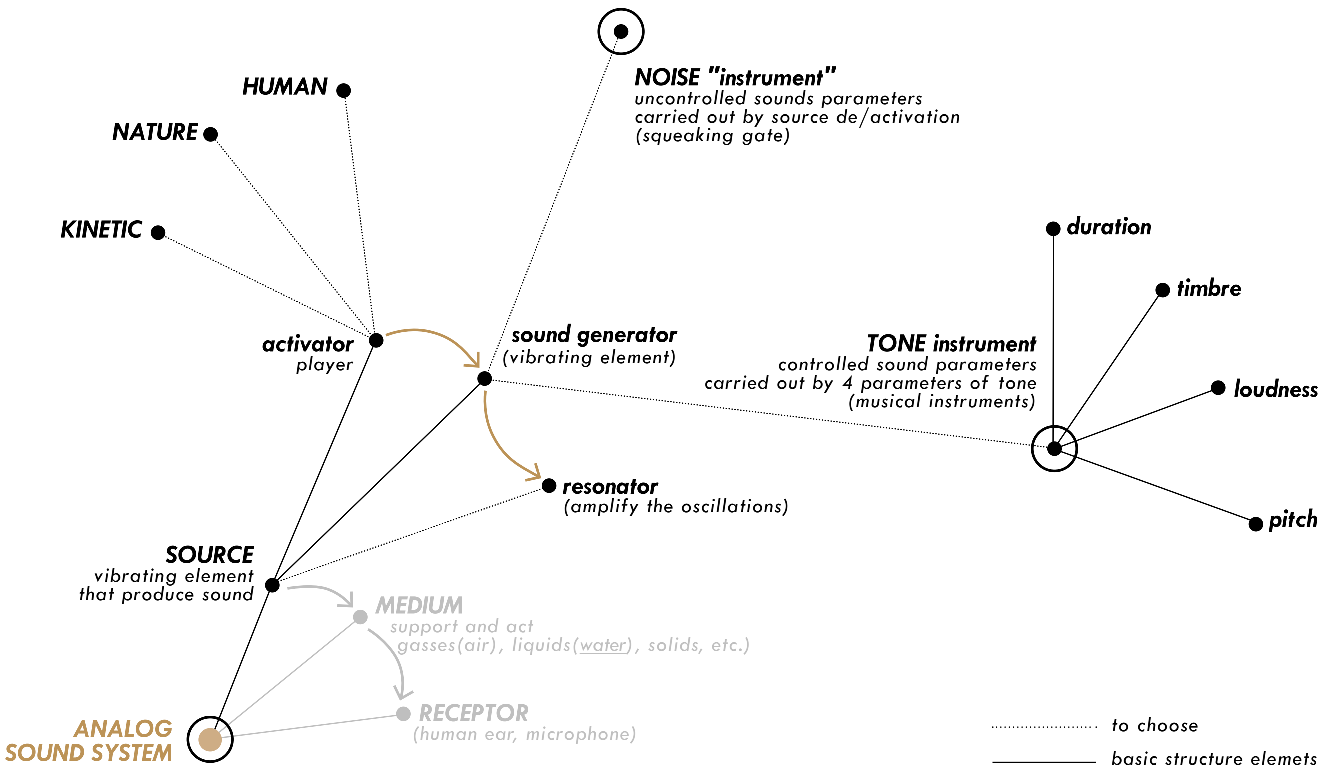


diagram S2 **"analog sound system"**

SOURCE

The source is a ***vibrating element*** or resonator that produces oscillation (waves). The source producing sounds need an ***activator*** -"player," vibrating element-***sound generator***, and sometimes a ***resonator*** to amplify the oscillations. *Diagram S2.*

In music as sources, we usually mean some instruments that produce ***musical sounds (tone)***, or in other words- musical instruments. For example flute, piano, drums or xylophone. They possess controlled pitch, loudness, timbre, and duration, attributes that make them amenable to the musical organization and control.

However, this is only a part of the sounds around us. "*That some sounds are intrinsically musical, while others are not, is an oversimplification. From the tinkle of a bell to the slam of a door, any sound is a potential ingredient for the kinds of sound organization called music". William E.Thomson, 2010, "Musical sound", https://www.britannica.com/science/musical-sound, last view: 25.10.2018*

Under "other" sounds we understand ***noises***- unstable or random acoustic oscillations characterized by a random variation of amplitude and frequency.

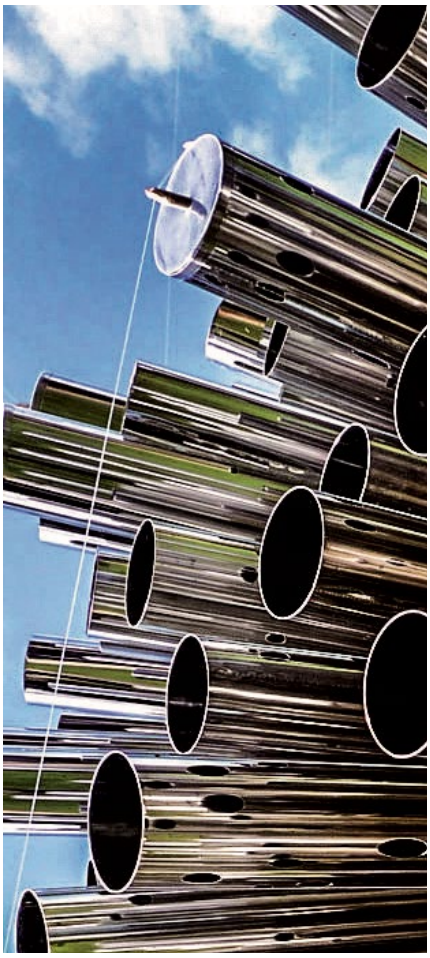


Photo S1

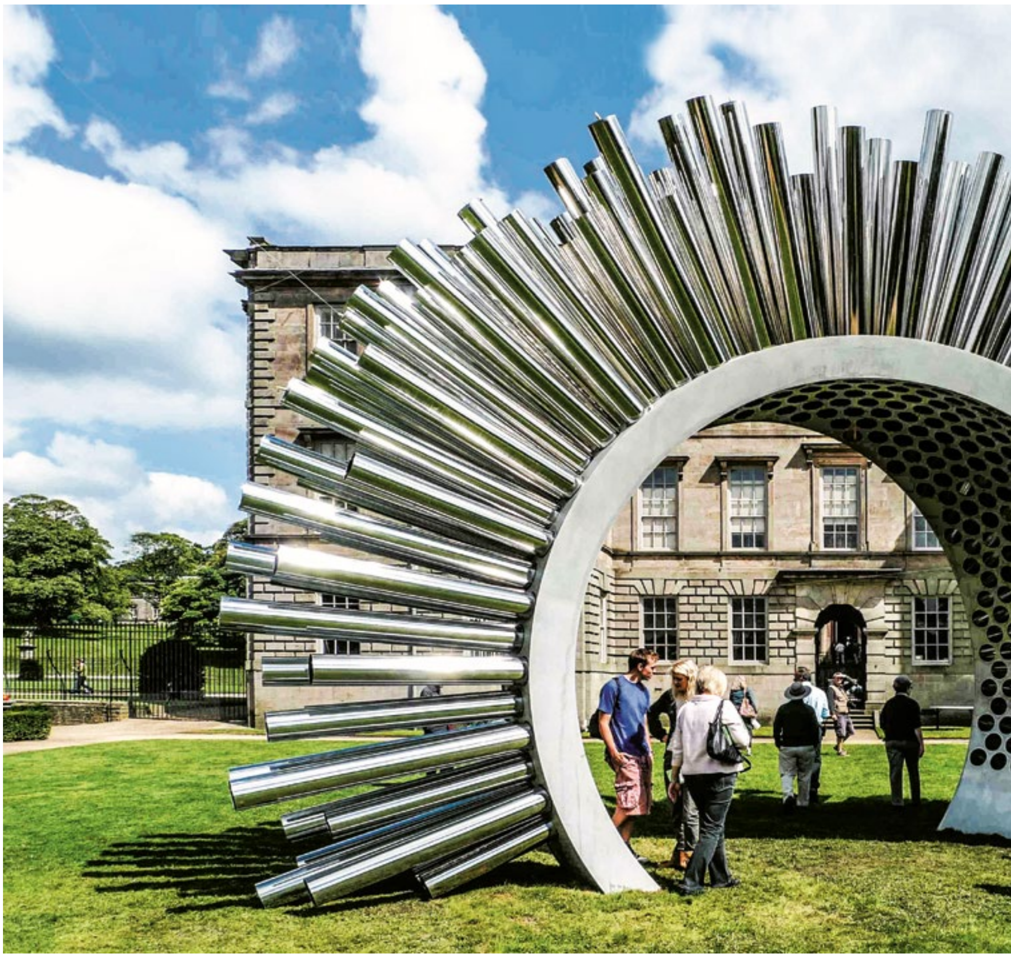


Photo S2. Aeolus, Luke Jerram 2011, Photos by lukejerram.com

activator

This is a primarily acoustic energy source. Here we can highlight ***human-, nature- or mechanical energy***.

For example, in a *photo S1, S2* musical pavilion with an analog sound system is depicted. In this project, the wind (***nature***) is an activator of strings vibrations that produce noises. The strings are attached to the tops of some tubes, thus transmitting the oscillations to their bodies. Finally, the vibrating body of the tube work as a resonator and produces air waves that we can hear.

Another example of an activator (***human***) showed on a *photo S3*, a violinist. Human produces the vibration of a string with the help of a violin bow. The body of a violin absorbs and resonates the oscillations and transmits them into the air.

sound generator

The most significant difference in the final sounding makes a sound generator type. As mentioned before, there are two types of sound waves generators: the ***tone generator*** with controlled sound parameters and the ***noise generator***, without control of a sound.

Tones or musical sounds allowed the creation of a musical notation system, which is understood by every musician. Also, they allow us to calibrate musical instruments through a ***pitch***, ***loudness***, ***timbre***, and ***duration***. The effect of being in the space full of noises will be different than being in a space full of tones (musical sounds).

"Music is fundamentally the balance between predictability and variability". Jackson Jhin, 2015, TEDx, "Transforming Noise Into Music"

This statement applies not only to the rules of sounds structurization and composing (section ***rules***) but also sound types. There is no single right choice. In a spectrum where

activator: *wind (nature)*
NOISE generator: *strings*
resonator: *metal tubes*

activator: *human*
TONE generator: *strings*
resonator: *wooden corpus of violin*

Photo S3. Violinist Photo by O. Cameron

on one side there are tones, and on the other side noises, the author can move freely in any direction[1]. Different ideas and projects will require different choices.

resonator

A resonator is a device with resonant properties, that response to a specific frequency oscillation stronger than to oscillations with other frequencies.

Although we use the resonators in various fields of technology, in music, they are particularly important since many musical instruments use resonators to enhance the intensity of sound.

The products of a resonator are standing waves that are enclosed at its length by a different number of times, and, consequently, have different wavelengths and are called its normal modes[2]. The whole number of the normal modes of the resonator determines its spectrum, or, in acoustics, the timbre.

1 John Cage for exemple, composer whitch music is extreme variabile (aleatoric music), worked with noises and with tones. In a same extreme variable context, the sounding and the effect of the compositions with tones and noises are very different. Exemple "String Quartet in Four Parts"(1950) and "Branches "(1976).

2 "So the resonant frequencies of resonators, called normal modes, are equally spaced multiples (harmonics) of a lowest frequency called the fundamental frequency. The above analysis assumes the medium inside the resonator is homogeneous, so the waves travel at a constant speed, and that the shape of the resonator is rectilinear. If the resonator is inhomogeneous or has a nonrectilinear shape, like a circular drumhead or a cylindrical microwave cavity, the resonant frequencies may not occur at equally spaced multiples of the fundamental frequency. They are then called overtones instead of harmonics. There may be several such series of resonant frequencies in a single resonator, corresponding to different modes of vibration." Wikipedia (last edited 2018): Resonator, https://en.wikipedia.org/wiki/Resonator, last view: 28.10.2018

sO

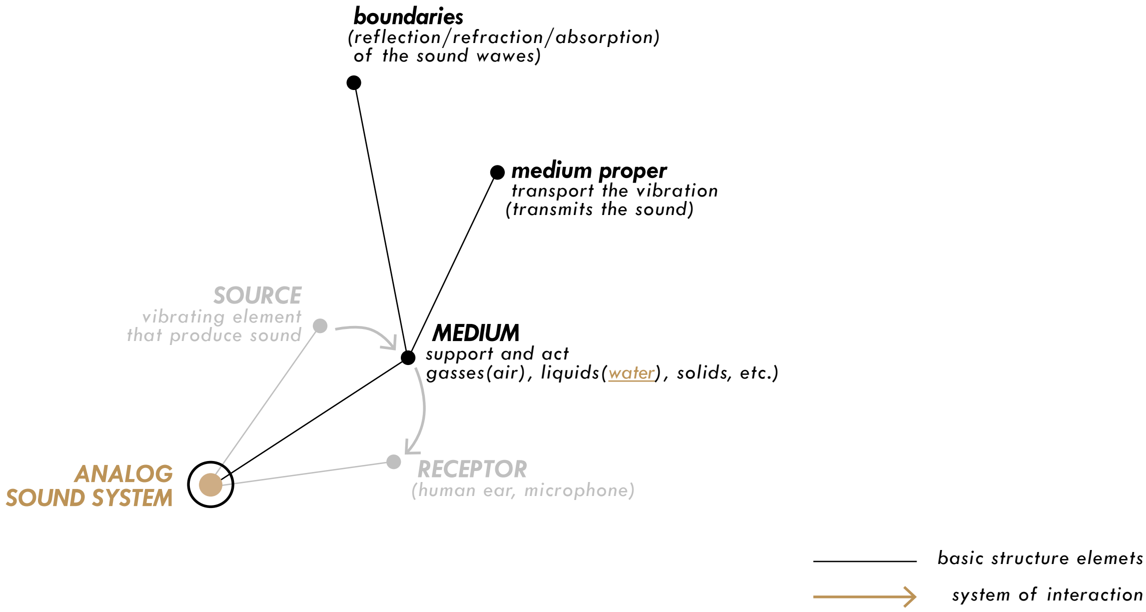


diagram S3 **"analog sound system"**

MEDIUM

The material that the sound travels through is called "acoustic medium," and without it, sound cannot travel at all. That is why sound does not exist in a vacuum[1]. Generally, many materials can support sound and act as acoustic media: liquids, solids, gasses, and even more obscure forms of matter like plasmas. The medium also determined such essential sound features as sound speed, sound absorption, reflection or refraction. Generally, we can highlight two groups of these parameters: ***medium proper*** properties, and its ***boundaries***.[2]

1 Northwestern University (2017): Space Environment, Is there sound in space?, http:// www.qrg. northwestern.edu, last view: 28.10.2018

2 Roederer, Juan G. (2008 [1973]), 4th Edition: Physics and Psychophysics of Music, The Intervening Physical Systems, p.3

medium proper

Medium proper in the propagation of sound waves[3], is a specific mechanical motion of particles of the medium. In gases and liquids, the sound propagates like a longitudinal wave, that is, as a sequence of compressions and extensions. In solids *(Photo S4, S5)*, in addition to longitudinal sound waves, transverse waves may also be distributed in which oscillations occur in the direction perpendicular to the direction of propagation.

Longitudinal and transverse waves propagate at different speeds. In isotropic media, the propagation rate of perturbations does not depend on the direction.[4] In anisotropic media, such as crystals, the anisotropy of velocity is observed when the speed of sound varies depending on the direction of propagation.

3 demonstration of sound waves propagation in the air: SKUNK BEAR, 2014, "What Does Sound Look Like"; in other mediums: Nigel Stanford, 2014, "CYMATICS: Science Vs. Music"

boundaries

The boundaries of medium make a significant difference in a sounding quality, strongly affect on the propagation of the sound waves by its absorption, reflection or refraction.

In architecture, it will be a quality of a room acoustic. In this case, everything that is around us (floors, walls, furniture) and also people in the room make an impact on a sound propagation (reverberation, echo). Topic of a boundaries of the sound medium is essential in architecture and is explored in the acoustics

4 Wikipedia (last edited 2018): Sound, https:// en.wikipedia.org/wiki/Sound, last view: 28.10.2018

Photo S4. "Swimming" Rolf Julius 1999-2013, photo by galeriethomasbernard.com

Photo S5. "Blue (yellow)" Rolf Julius 2009, Photo by galeriethomasbernard.com

Photo S6 "The Silent Room" Nathalie Harb in collaboration with BÜF and 21dB, London Design Biennale 2018. Photo by londondesignbiennale.com

In ***acoustic architecture***, the control of tone and noise is essential. Specific functions, such as church, opera house, recording studio, anechoic chambers, school, libraries, etc. needs specific properties of medium to control the quality of sounds propagation, absorption and reverberation in the space.

Photo S6 «The Silent Room» pavilion, London Design Biennale 2018. "Silence is becoming a commodity for the privileged," says designer Nathalie Harb.

To live in an urban environment is to be subjected to a torrent of information and distractions, while public space is disappearing in a relentless wave of privatization. The Silent Room responds to this context, providing a cocoon- like space isolated from the city noise.

Photo S7,S8 different project but with the similar parameters. The main requirement for the medium-noise absorbation. Apple's antenna design lab 2010, "black lab", is a wireless testing lab, that consists of several anechoic chambers to measure the frequency of each device in various settings.

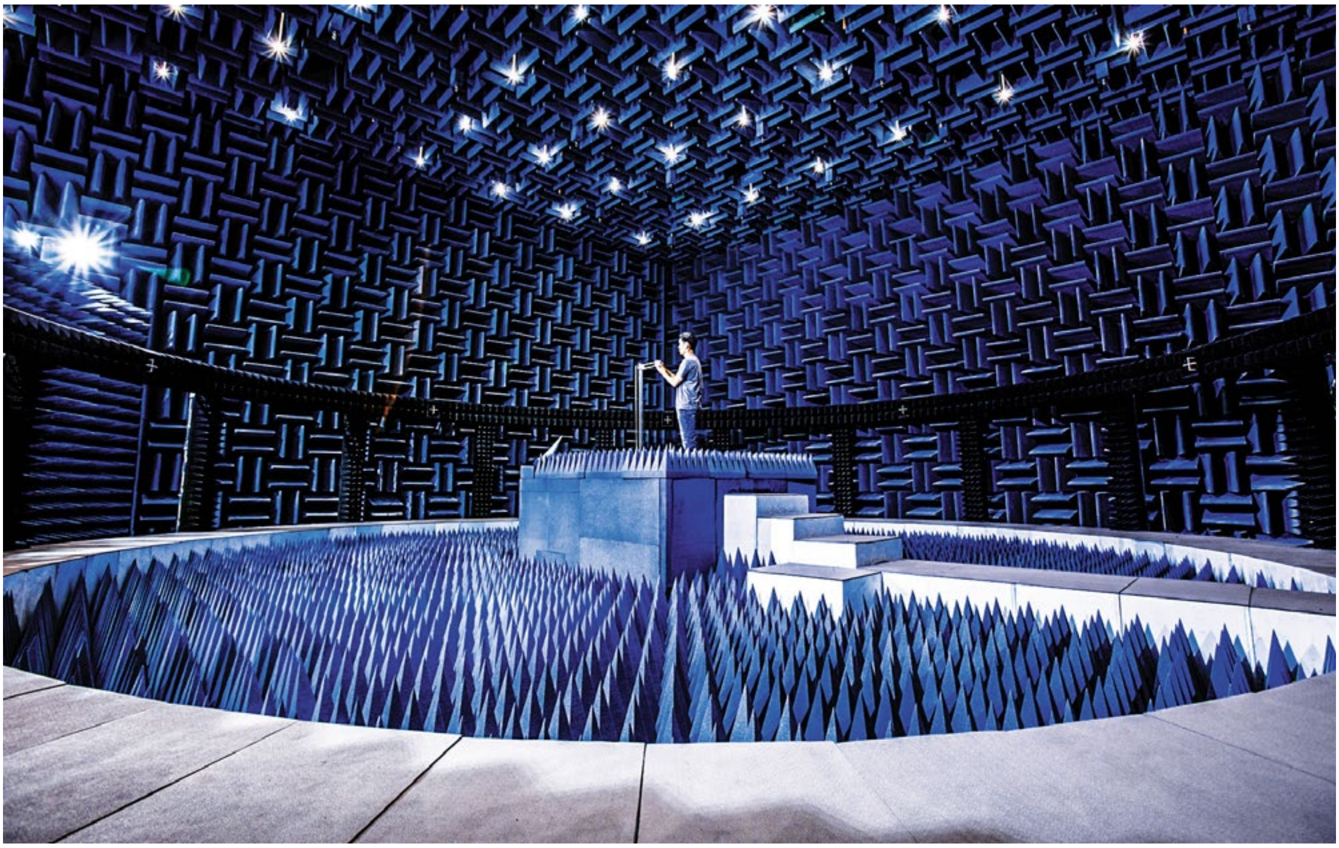
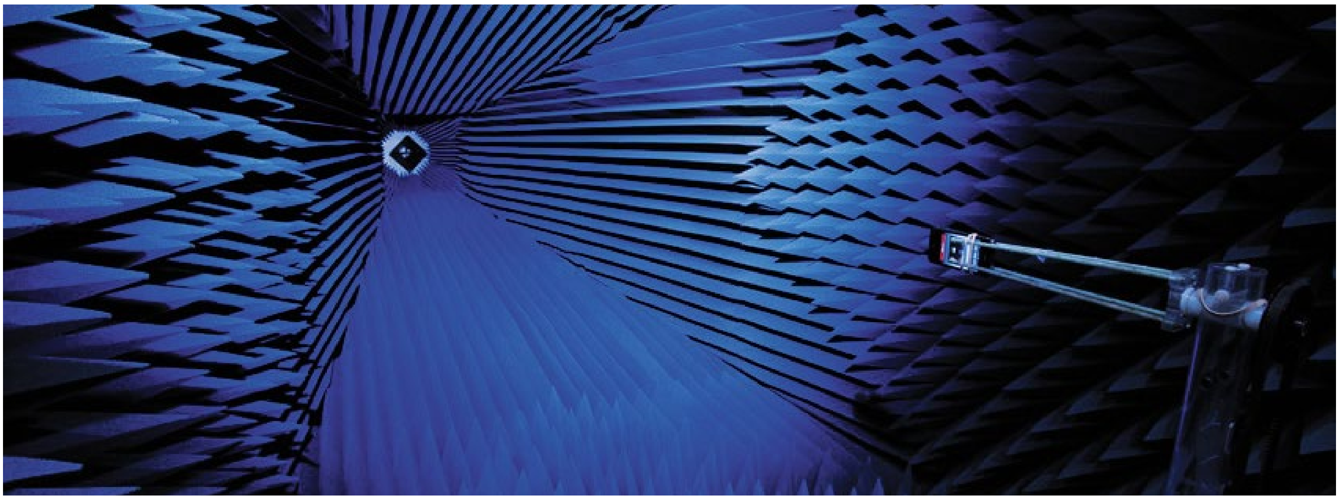


Photo S7. "black lab" Apple 2010
photo by wired.com

Photo S7. "black lab" Apple 2010
photo by wired.com



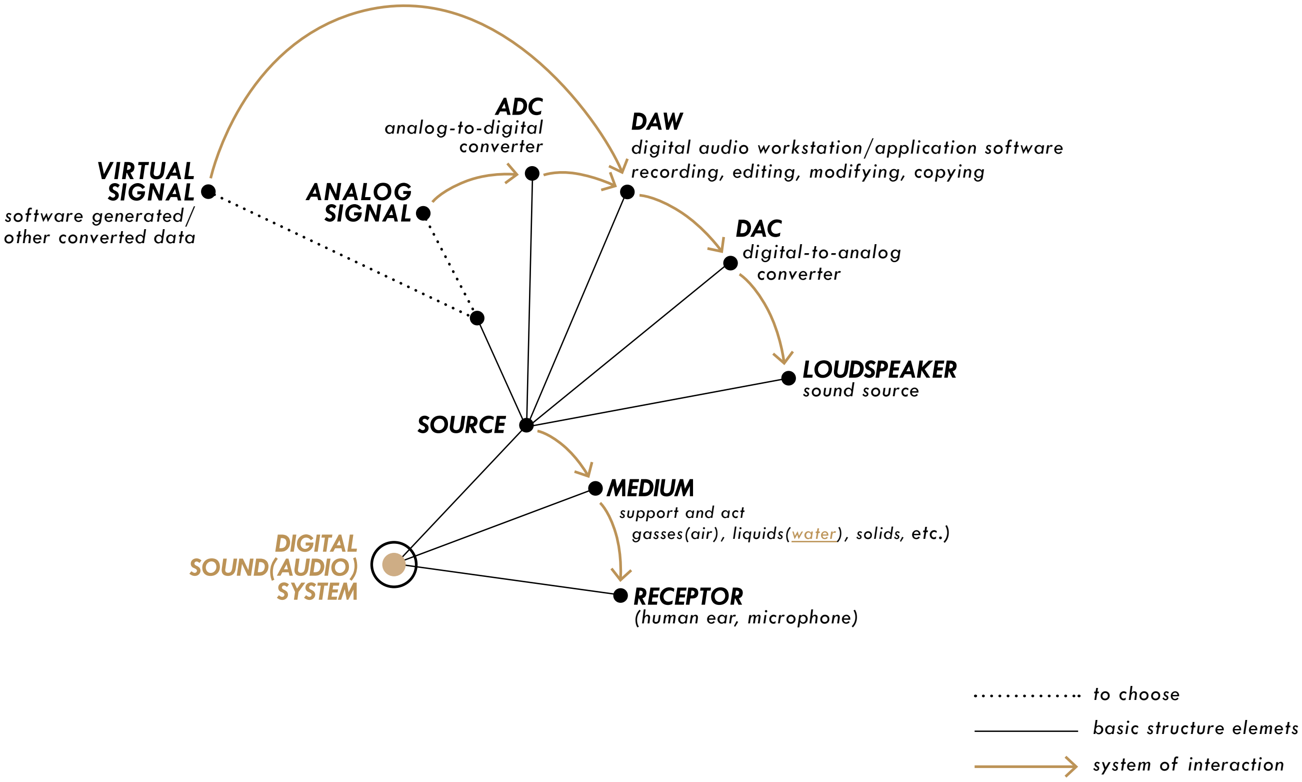


diagram S4 **"sound systems"**

DIGITAL SOUND SYSTEM

or digital audio system is *"the name for the entire technology of sound recording and reproduction using audio signals that have been encoded in digital form."*[1]

As a analog system, the digital audio system consists of a sound source, medium, and receptor. The main difference between them lies in the sound source part. In the analog system sound waves are generated by a sound source and immediately travel through the medium(air) to the receptor.

In a digital system before this steps, the sound is going to be transformed. To provide this transformation a digital audio systems need the next elements: ACD (analog to digital converter); DAW (digital audio workstation) or application software for recording, editing, modifying, and copies of digital signal; DAC (digital to analog converter) that convert a digital signal back in to an analog signal; and loudspeakers as sound generator. *See diagram SO4.*

Musical instruments of sound transformation or generation and transformation, used by digital audio systems are called ***Synthesizers***.

There are two types of synthesizers: analog and digital.

The ***analog synthesizer*** generates sound electrically, using electronic systems (analog circuits) that works by proportional relationships between a analog signal and voltage (samplers)[2]

The ***digital synthesizer*** doesn't need an analog signal. Any digital signal can be used for sound generation.

Some digital synthezisers dont even need an digital sygnal or data. By software synthesizer and virtual analog synthesizer the sound can be prodused virtual.

In this area, there are a lot of interesting prototypes, that make us look at the process of music creation from a completely different angle.

For example, MiMu gloves project, where a virtual signal is generated

1 Wikipedia (last edited 2018): Digital audio, https://en.wikipedia.org/wiki/Digital_audio, last view: 28.10.2018

2 Wikipedia (last edited 2018): Analog synthesizer, https://en.wikipedia.org/wiki/Analog_synthesizer, last view: 28.10.2018

photo S8 ***"mimu gloves"*** *photo by mimugloves.com*

photo S9 ***"The Gloves Project" by mimu 2012***
photo by plusea.at

not by a keyboard, but by a wearable technologies (gloves).

Or like musical projects, that uses data from not acoustic sources for the virtual music creation. As for exemple in a project *"The Sound of Data"* Gabriel Levine, 2016. The author transformed wether data streams into a musical piece.

SOFTWARE AND RULES

By digital approach, important is a application software, that you use for the music creation itself.

Good softwares alowd us to program the rules of music generation intelegently. So that the people without a special musical education could also interact with the instrument and this process was relaxed, interesting and very intuitive.

The texture of the music, it's foreground, middle, and background can be designed as a variety of different types of sounds attached to different keys. Rhythm, dynamics, melody, harmony, tone colors, all of them are parameters that can be transformed (as one element or all together) by the software. You can choose which parameters are staying unchangeable and which can be variously transformed or even generated by other people.

A significant range of opportunities for experiments in this direction is revealed by touch sensors. The signal from a touch sensor can be converted into a MIDI signal (ADC) and can be used by an software for music creation.

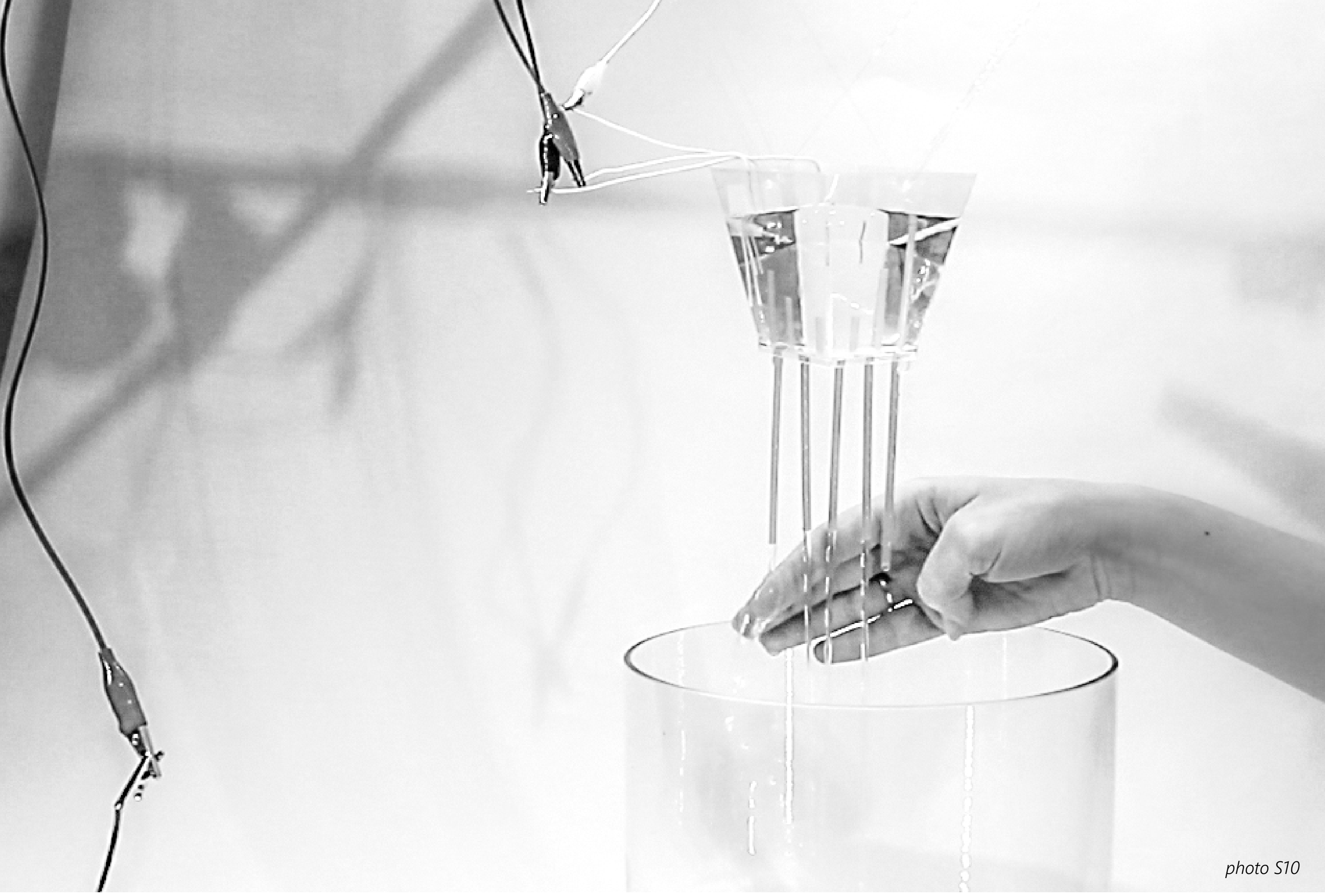


photo S10

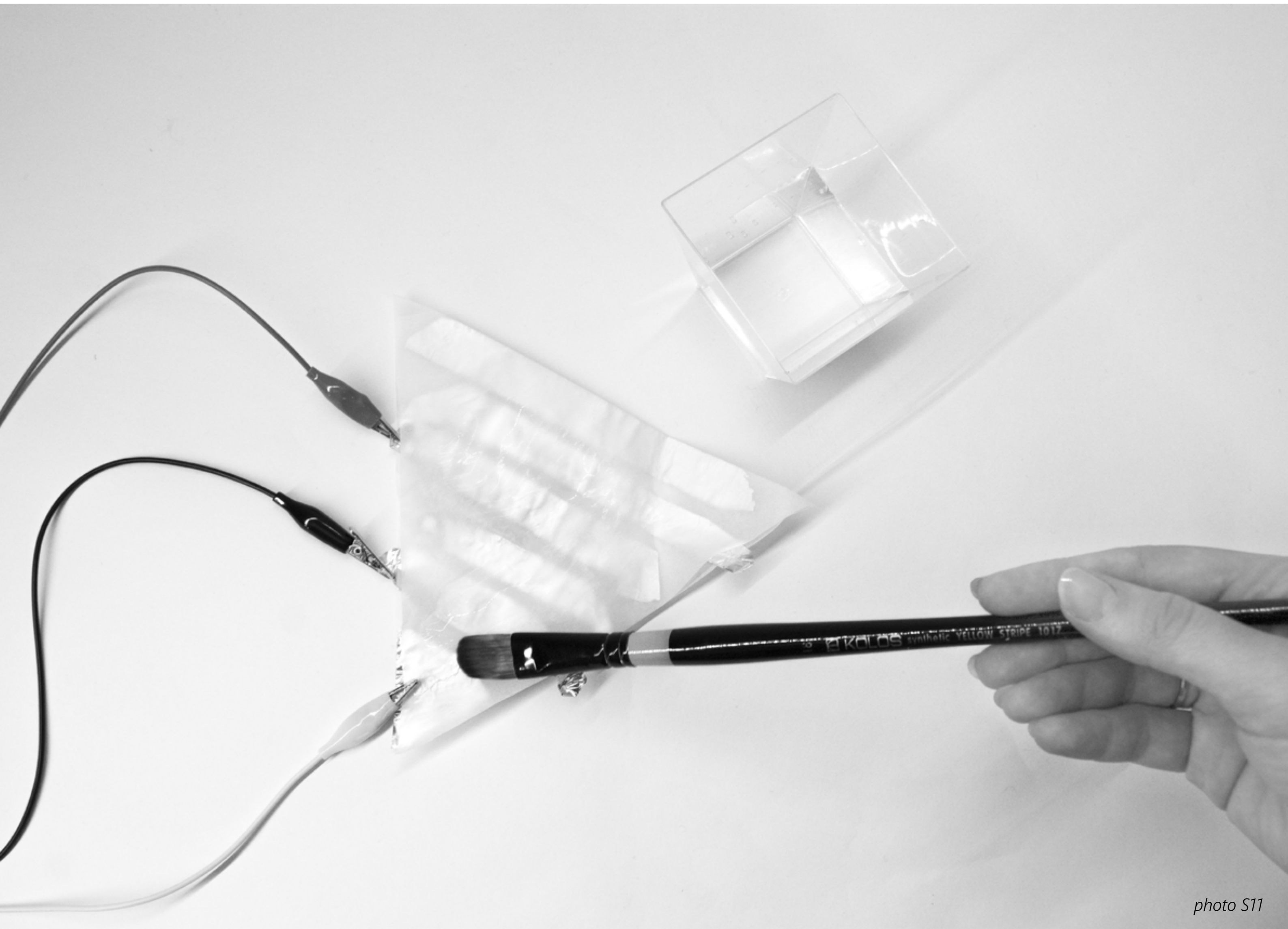


photo S11

SO

DIGITAL SOUND

EXPERIMENT S1

S1

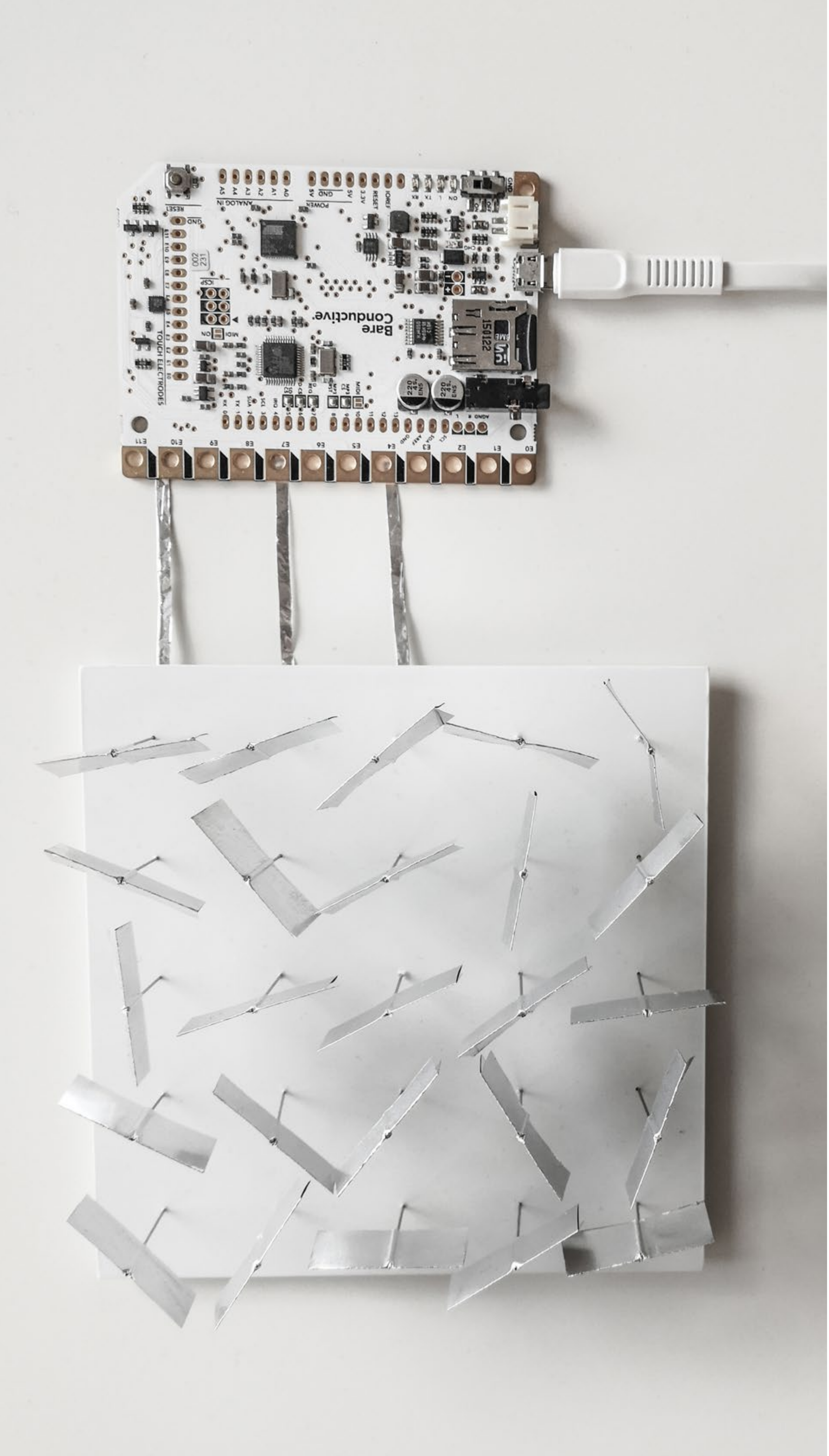
In this experiments, was used the touch sensor controller and ADC that produce a midi output signal as one system, realized in a ***BARE CONDUCTIVE*** board.

The ***BARE CONDUCTIVE*** touch board sends a converted touch signal via USB into a software (in my case ***ABLETON LIVE*** (programm for sound generation). To generate a signal you will need some conductive "buttons" as environment input.

In this experiments I tried to find out if the water cood be a conductive button. On the *photo S10*, the water in a vessel is connected with three sensors via three wires. Every wire is connected to the vessel wall and is located lower than the previous one.

During waterfall you can touch any of the 5 jets of water, producing an touch signal of 3 notes. During this process software generated a melody with different pitches of note.

On the *photo S11* shows other variations of signal generation. In this case aluminum-folie strips are conductive buttons. They are located under a thin upper layer of paper. Painted with a water on a paper I made some footprints that produce a connection with touch sensors and generate sounds.


Bare
Conductive

DIGITAL SOUND

EXPERIMENT S2

I this experiment I focused on the question: Is it possible to use nature as an energy source for sound generation in a digital-virtual sound system in the real-time mode.

The answer is: yes, it is. The photo on the left side shows a fairly simple system of wind power implementation for this goal. Propellers in the system, as well as pillars, are made from conductive materials.

When the wind blows, the propellers begin to rotate. They touch each other, generating at the moment a touch signal (same signal as in a previous experiment).

The base plate has on the back side connection between the propeller pillars in the system, and a touch sensor. In this experiment was also used ***BARE CONDUCTIVE*** touch board and ***ABLETON LIVE*** software.

This approach can be implemented in architecture in the facade systems. For example for wind facade like in Ned Kahn projects: *"Vertical canal"* 2008, *"Articulated cloud"* 2004, or Charles Sowers project: *"Windswept"* 2012.

This approach allows not only to see the wind but also to hear his melody, using a "digitized" version of analog wind harp instrument (*Aeolian harp*)[1].

1 *"An Aeolian harp (also wind harp) is a musical instrument that is played by the wind." "The Aeolian harp – already known in the ancient world – was first described by Athanasius Kircher (1602–1680) in his book Phonurgia nova (1673)". "The motion of the wind across a string causes periodic vortices downstream, and this alternating vortex causes the string to vibrate." Wikipedia (last edited 2018): Aeolian harp, https://en.wikipedia.org/wiki/ Aeolian_harp, last view: 28.10.2018*

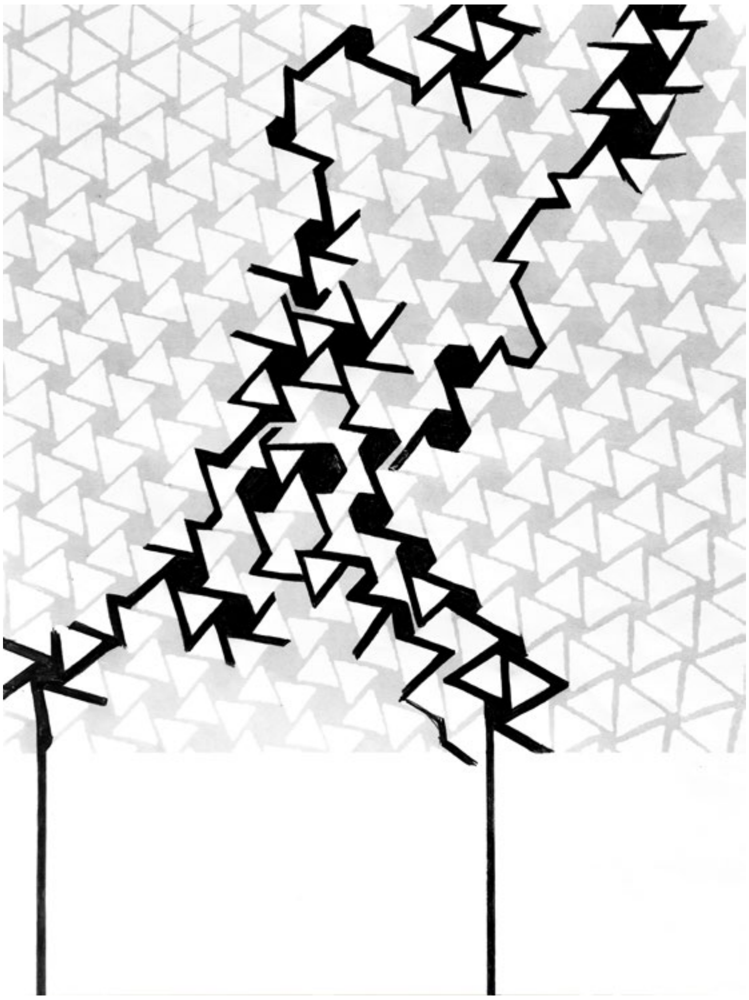


photo S13

photo S14

SO

DIGITAL SOUND

EXPERIMENT S3

S3

In this experiments, I worked with conductive paint as a touch sensor for music generation. As in previous experiments S1, S2, based on ***BARE CONDUCTIVE*** touch board and ***ABLETON LIVE***.

P*hoto S12* shows graphite painted pattern in A4 scale. By touching with fingers those graphite lines can produce a signal that is converted into sound.

On the *photo S13* the same approach is shown, but in the larger scale (A0). IIn this experiment, I tried to provide a sound during the dance. The graphite lines began to sing, while touching a foot.

Creating such kind of conductive surfaces can be interesting for educational places (kindergarten, schools), or for exhibitions and performance.

Convincing example"*Touch-animated display*", created by the design studio Dalziel and Pow, 2017.

sO

photo S15 "***Space No.2***", *Naum Gabo, 1957-8*

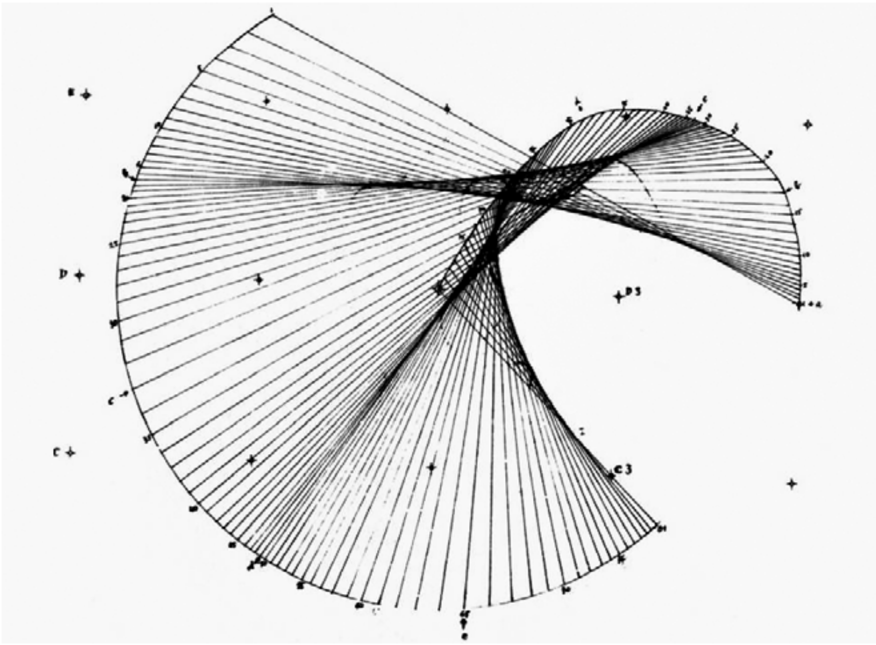


photo S16 " ***Polytope de Beaubourg***", *Iannis Xenakis, 1974-5*

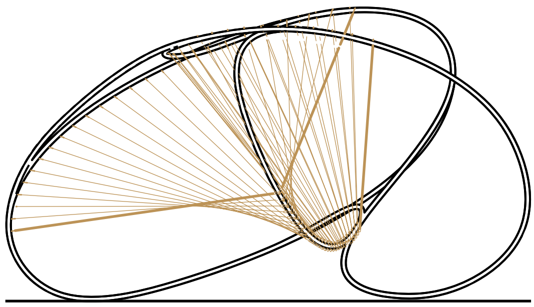
During the experiments with digital sound, I found it interesting to use a touch as data generator for MIDI signal. As we can see above, such an approach opens a lot of possibilities. Different types of conductive elements can be a part of the design, allowing the author to generate sound by not only typical buttons. Interestingly such systems can use an environmental input of wind or water for signal generation.

However, in the design process, I decided to work with more classical conductive material: brass strings. In the musical pavilion, a string is an intuitively understandable tool, from a perspective of touch, as a way to generate sound.

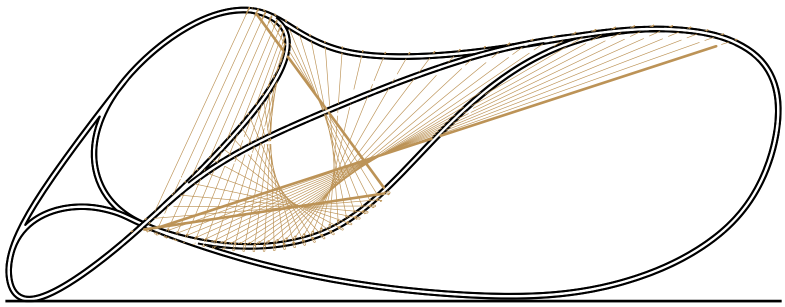
In addition, in the primary form of bearing structure in the pavilion (designed by using active-bending method), three strings were used for a form creation as bending elements, *photo S15.* In the final form, I found it important to leave those elements that no longer had the formative function but keep a reference to the process of forming *(drawing SP1, p.80)*.

The music component can give a new feature to those elements. By playing around with the different possibilities of placing of new strings, between three basic strings I come to the final design of a musical layer of the ***ARCOUSTICON*** pavilion.

The source of inspiration for design come frome: sculptures of linear construction in Space by avangarde sculpture, theorist and architect Nanum Gabo 1890-1977; and diagrames with rools of sound creation by architect and composer of aleatoric(stochastic) music Iannis Xenakis 1922-2001.

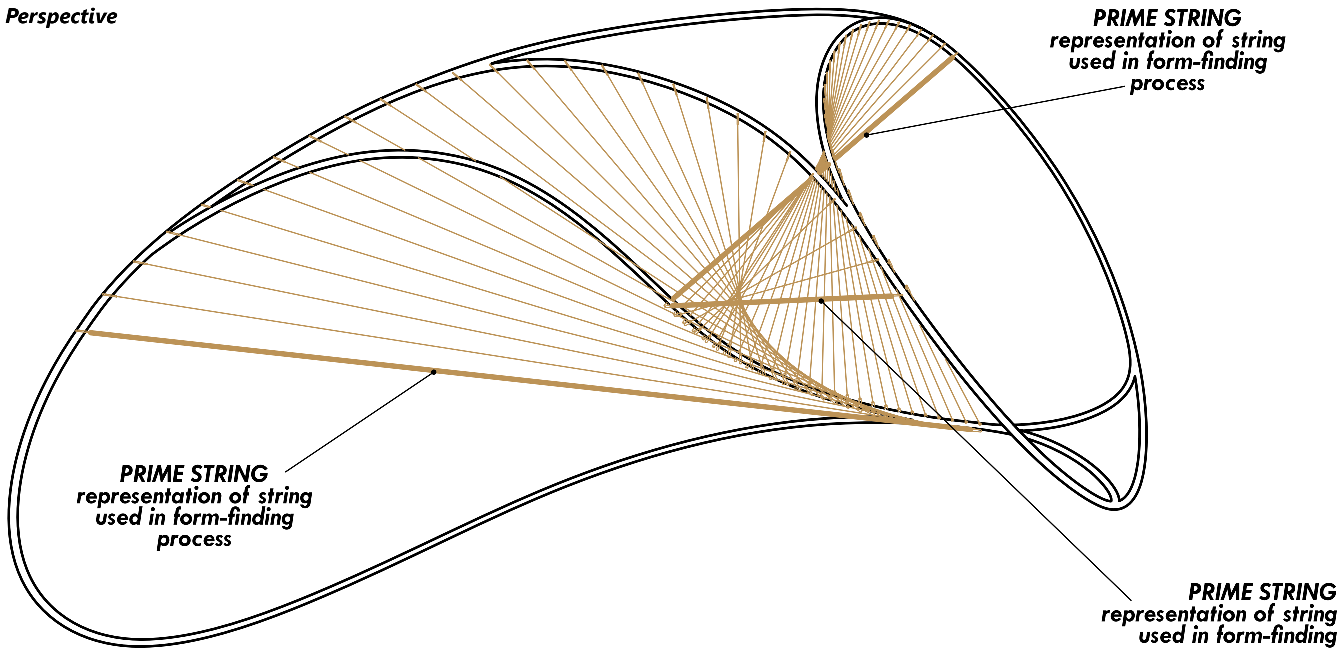


Side View



Front View

Perspective



MUSICAL TOOL

DRAWING S1
Front View, Side View,
M=1:1
Perspective

In the *drawing S1* are showed "prime strings", as representation of structural elements of the ***prime form***. These strings were used as main control elements by the ***active-bending form-finding process.***

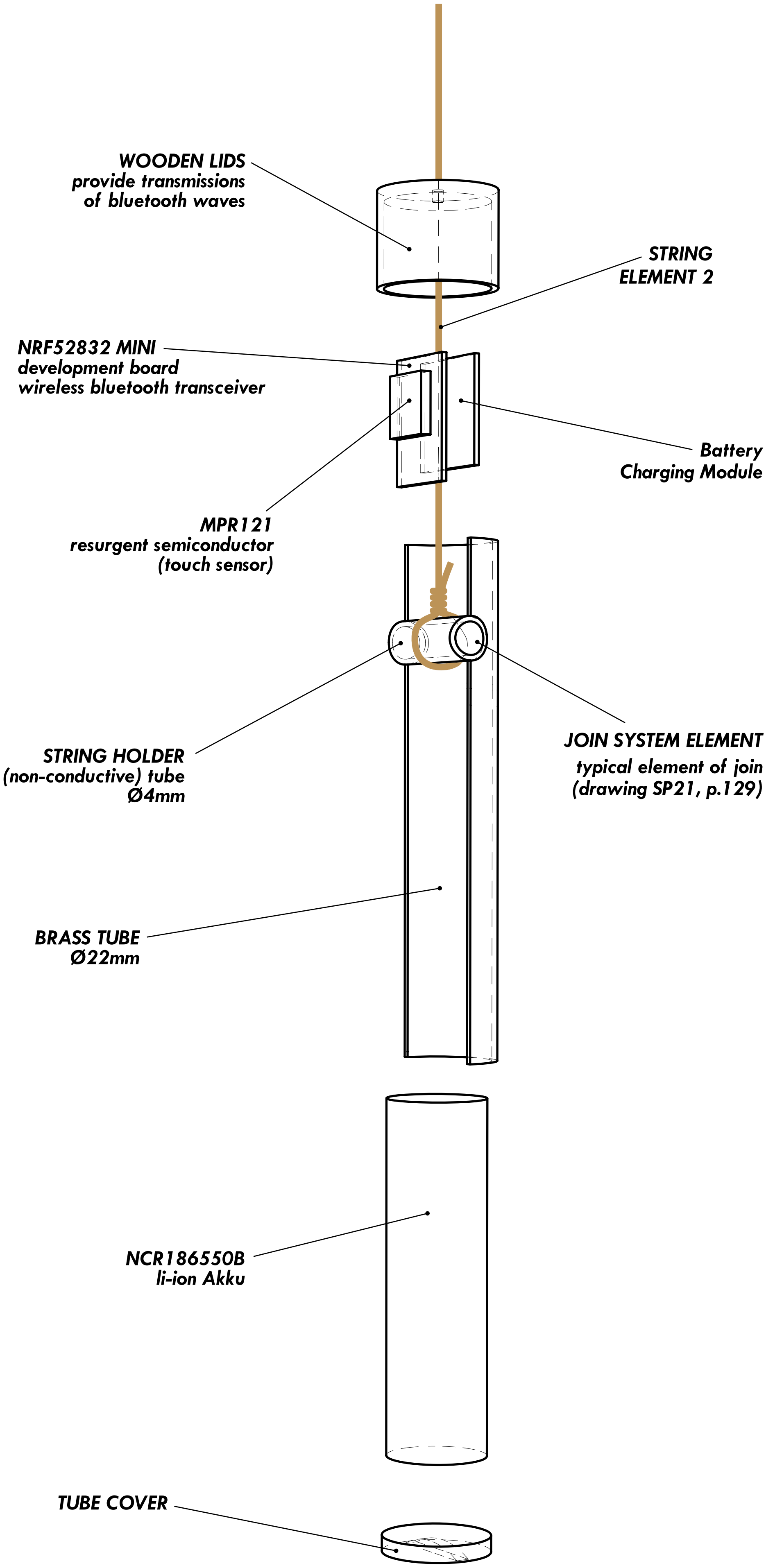
As the next step, I decided to use the space between this strings to implement all touch sensors (other strings) of ***ARCOUSTICON***. The points on some parts of a bearing structure are choused as upper and lower ends of the strings.

The rules, how these ends were connected, came from the idea of metaphorical representation of a dance in architectonic form. While the view angle is changing, a new form of Arcousticon opens up in front of observer. The form invites the visitor into a discussion, changing the shape while he moves, attracting to come closer and touch.

The system and details of the ***MUSICAL TOOLS*** are to be found on the next pages.

MUSICAL TOOL

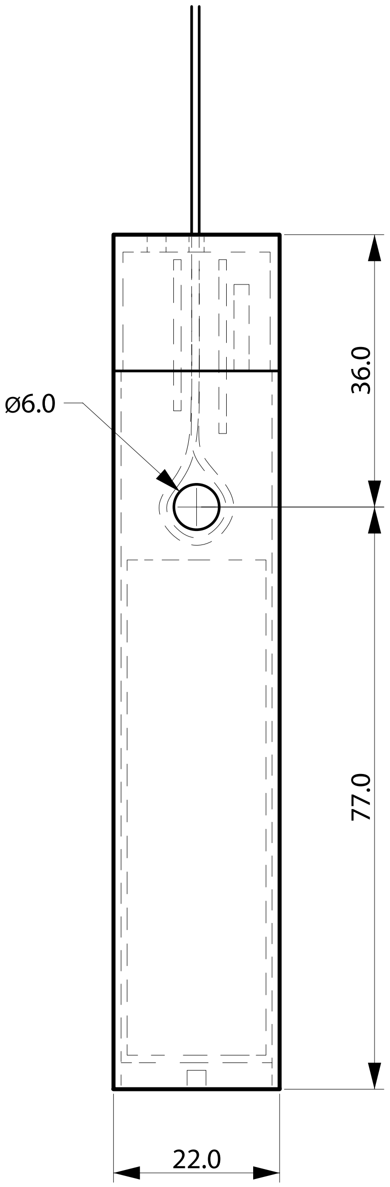
DETAILS, DRAWING S2
ELEMENT 1



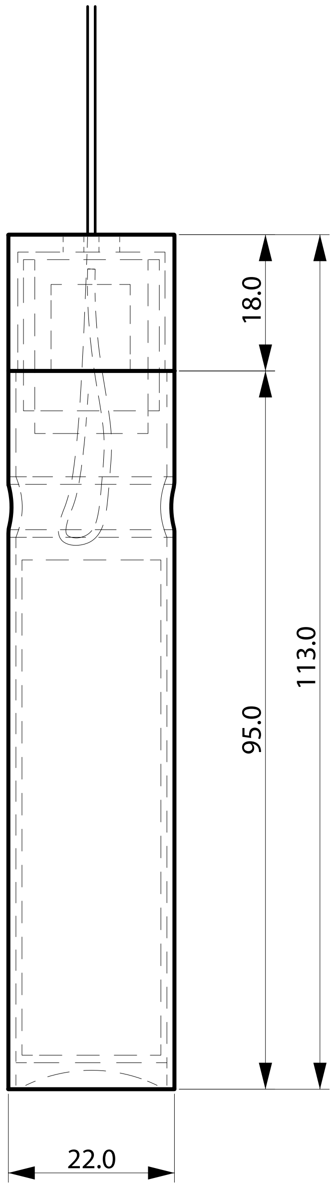
MUSICAL TOOL

DRAWING S3, ELEMENT 1
Front View, Side View, Top View, Perspective
M=1:1

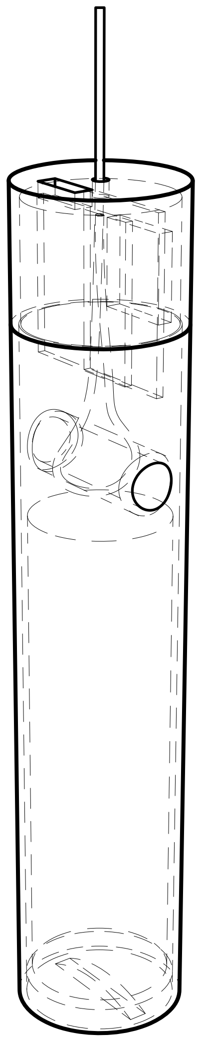
Front View



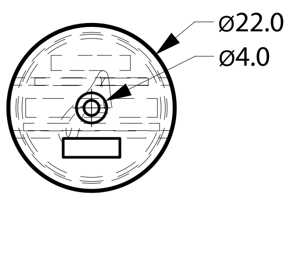
Side View



Perspective

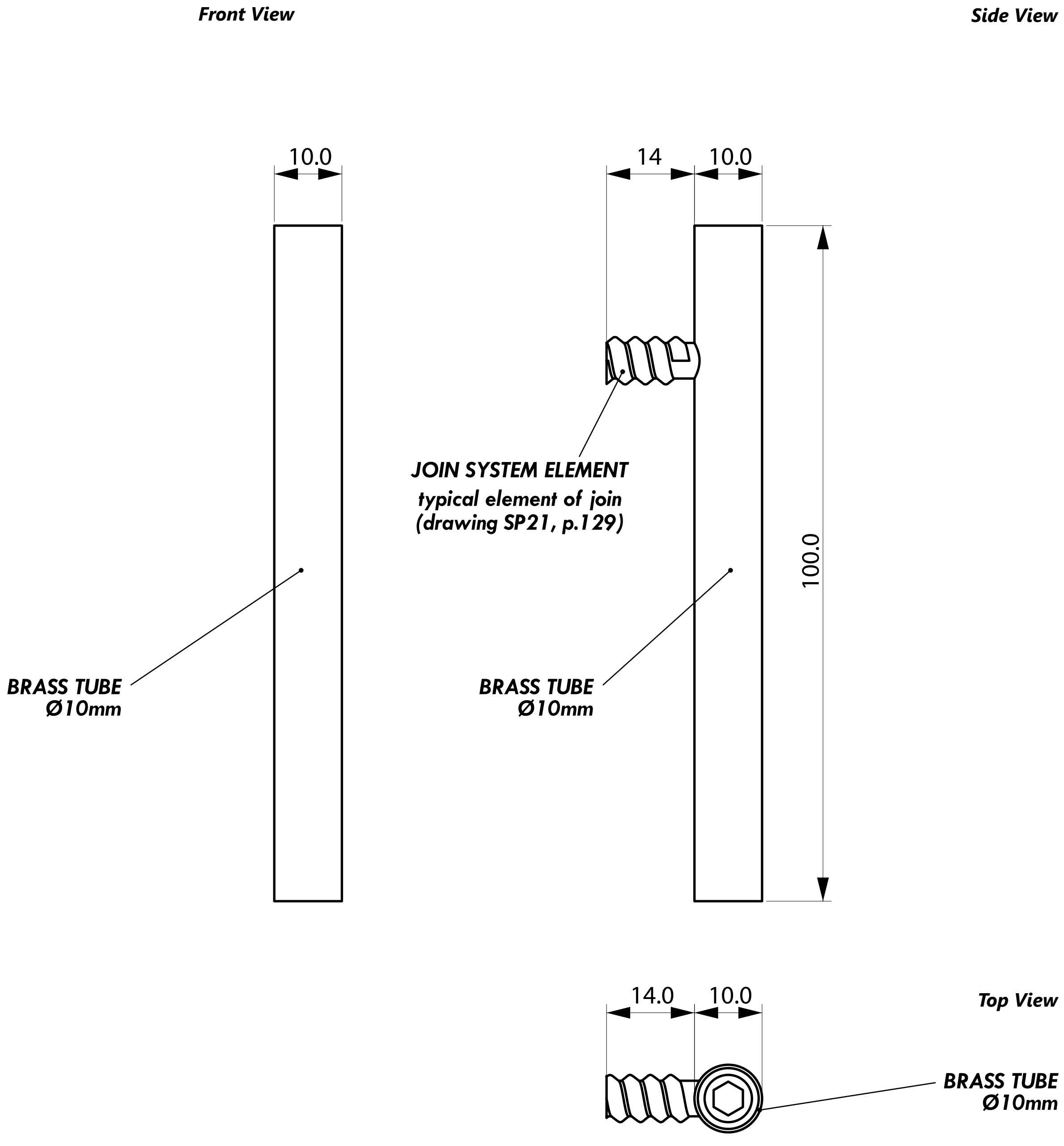


Top View

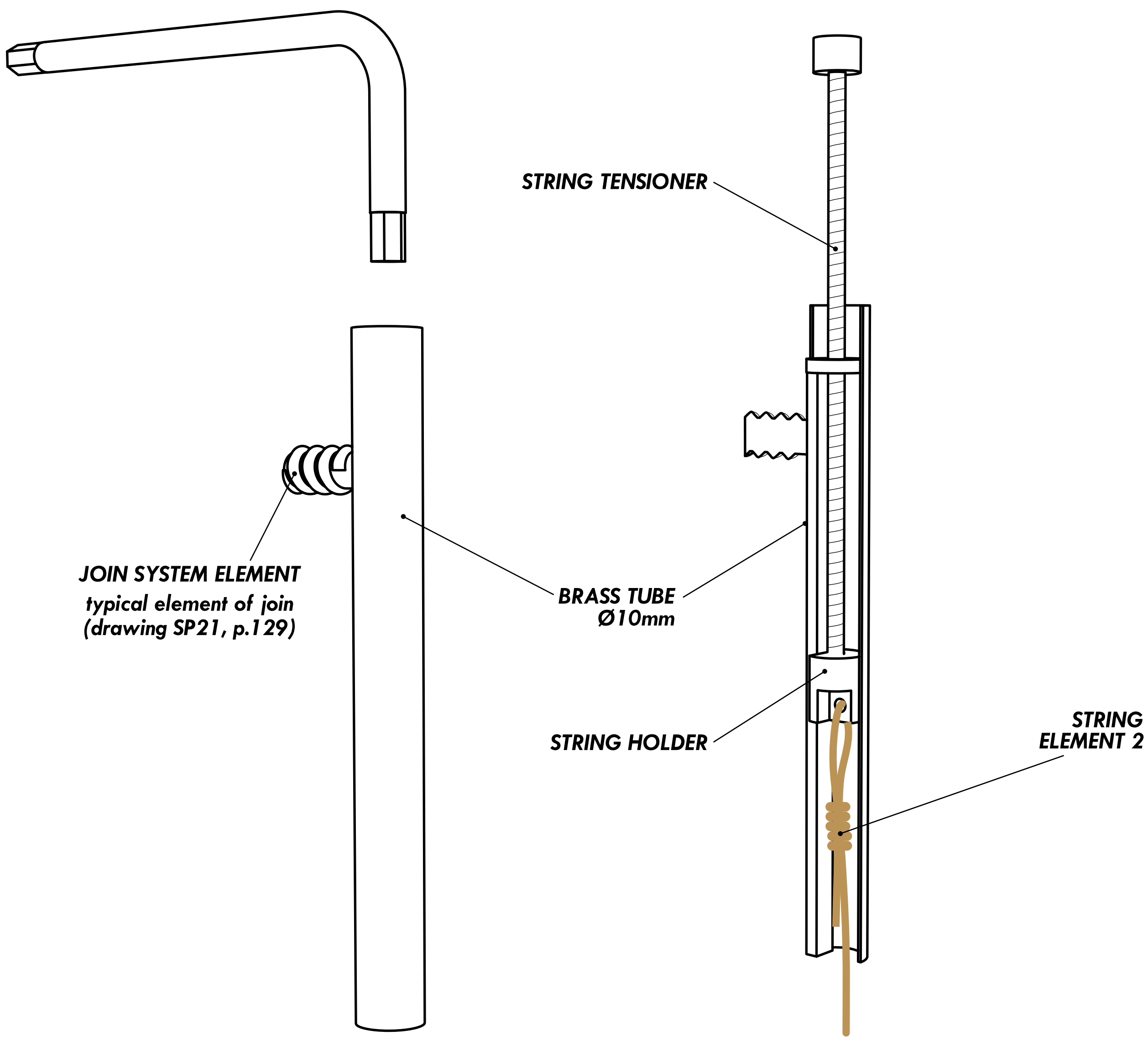


MUSICAL TOOL

DETAILS, DRAWING S4
ELEMENT 3
M=1:1

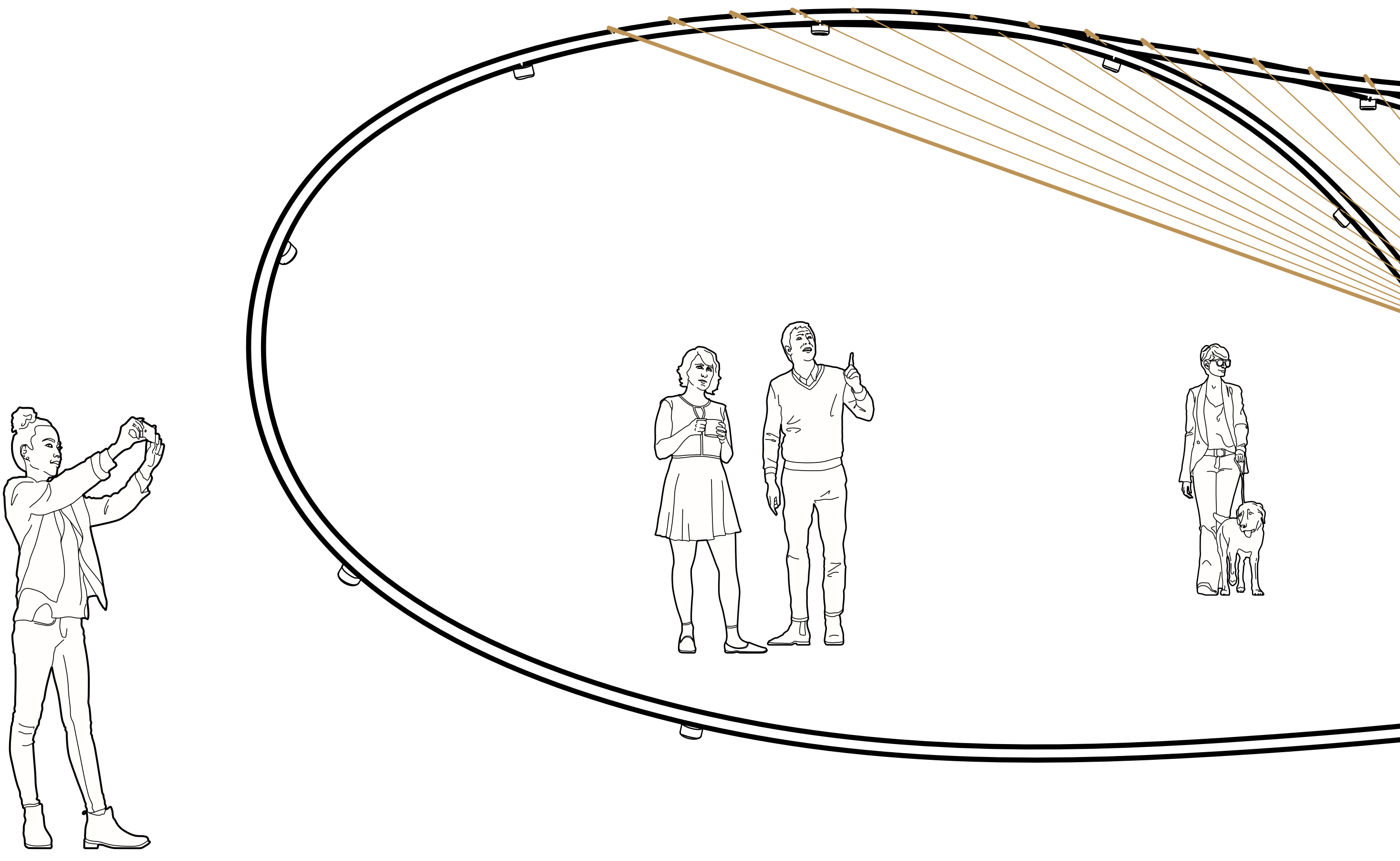


DETAILS, DRAWING S5
PERSPECTIVE

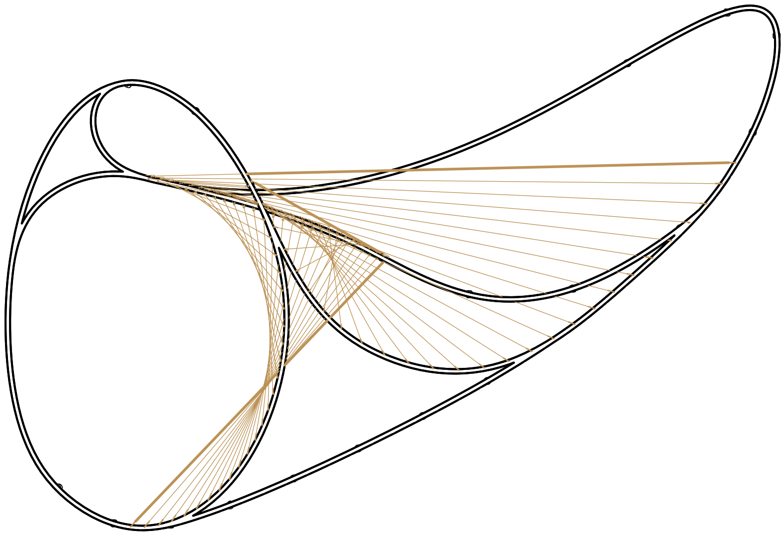


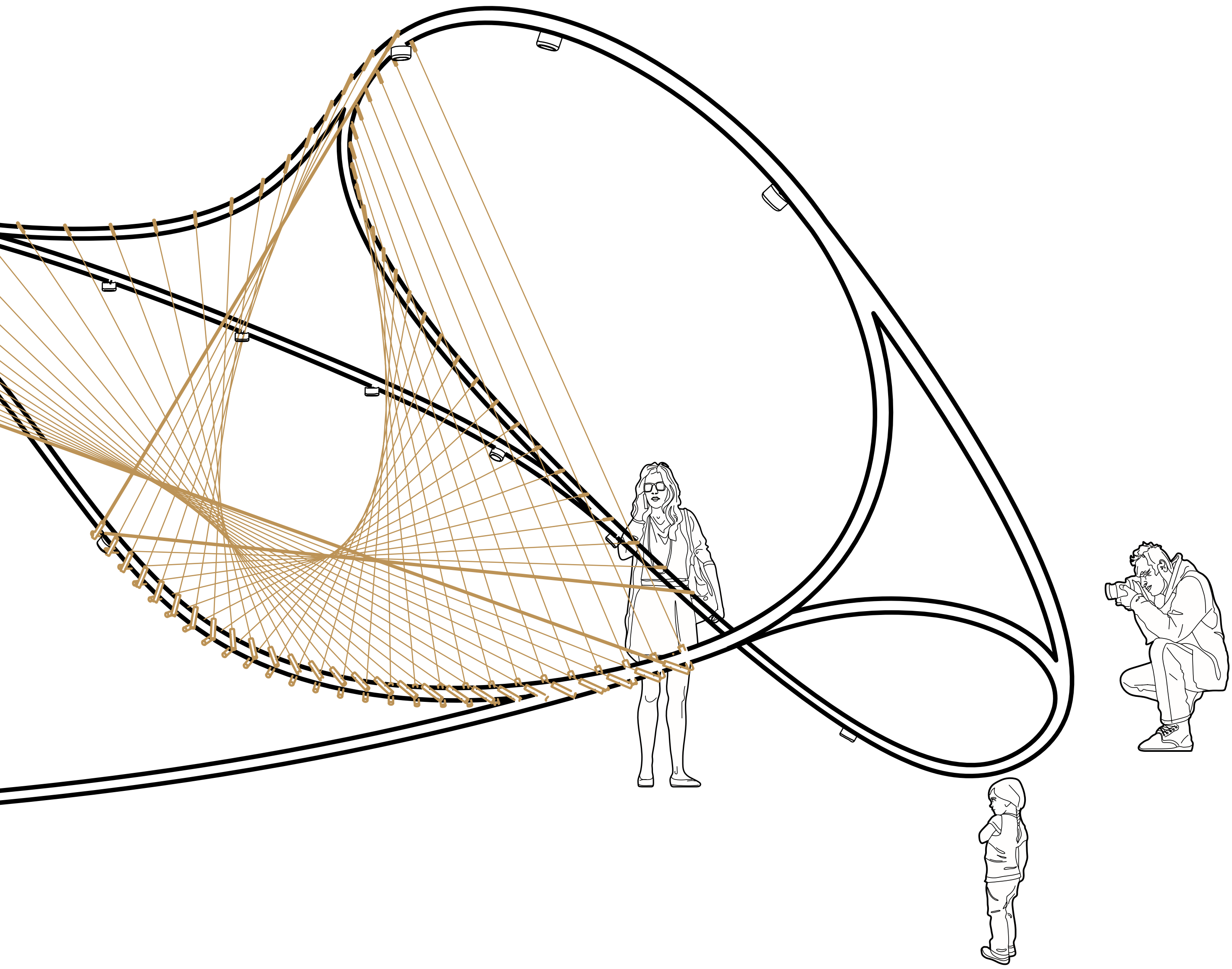
1.LAYER
BEARING STRUCTURE
+
3.LAYER
MUSICAL TOOLS
PERSPECTIVE VIEW

DRAWING S6



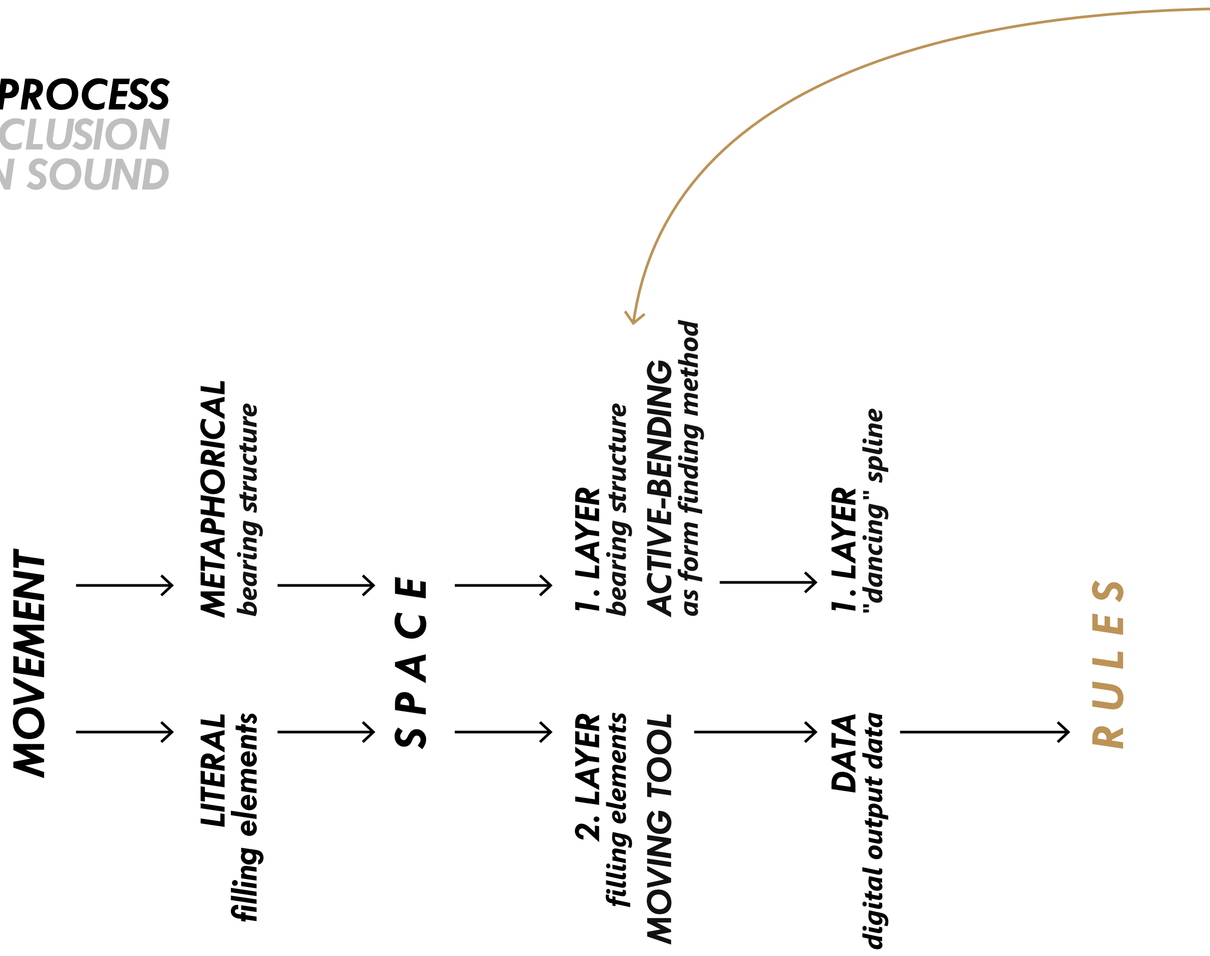
drawing S7
***Top View,** M=1:100*





sO

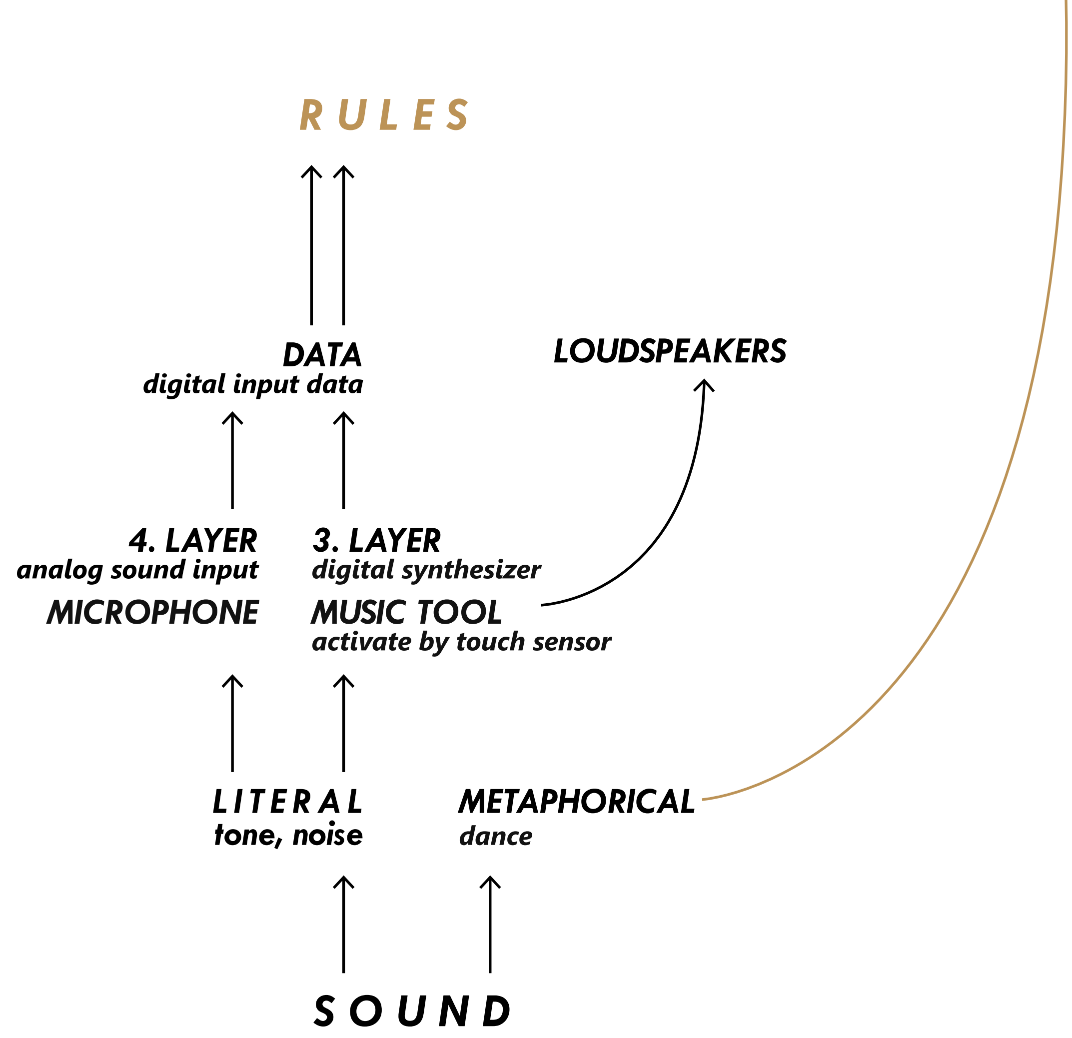
DESIGN PROCESS
CONCLUSION
SECTION SOUND



At this stage, all tools of interaction are developed: ***MOVING TOOLS*** and ***MUSICAL TOOLS***. The musical tool is designed as a digital synthesizer, that can be activated with a touch, and communicate with a software of virtual music generation by ***Bluetooth*** via ***MIDI*** interface.

Moving as well as musical tools are designed to be easily applied or removed from the structural ***1.Layer*** (bearing structure) of ***ARCOUSTICON***. With this approach, the designer can easily change the number of tools and its position for any performance.

The next step in the design process, is to found a system (rules) of tools interconnections and define the level of their influence on each other.



DESIGN PROCESS

RULES

RU

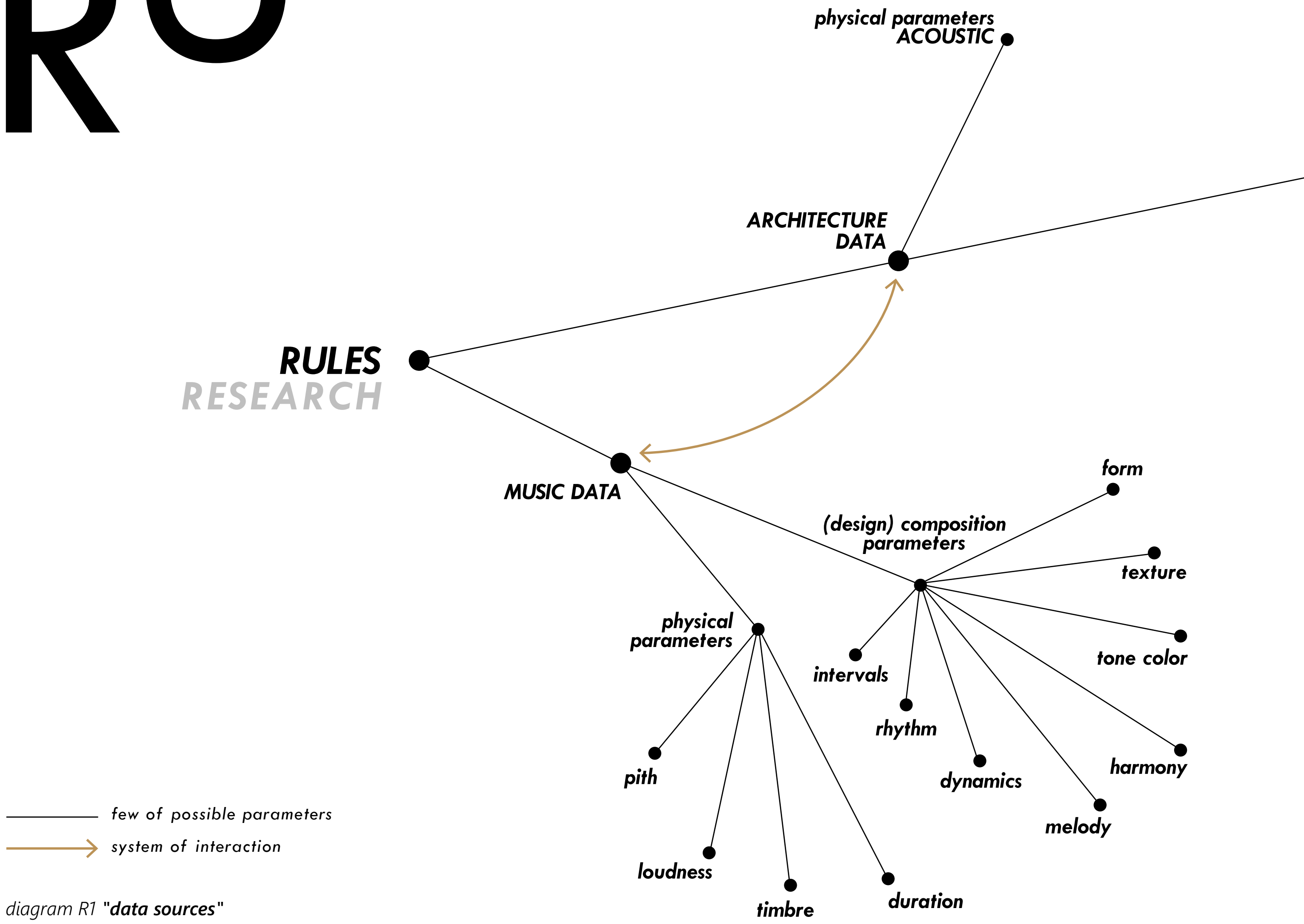


diagram R1 "**data sources**"

The rules in the context of musical architecture are an important part. Through rules, music can be translated into architectural language and vise versa. Words can be translated into different languages, so one idea can be understood by all humanity. The same happens in the architecture. Using the conversion of different data, we can express the same idea in many different disciplines.

It can be a translation of a global idea (the idea of a cosmic connection between music and architecture) or just a conversion of some particular parameters.

An example of sacral cosmic code (expressed in proportions) implementation was described on page 19, the project of Notre Dame de Reims. On the following diagrams are shown systems of sacral harmony (proportions) in music, especially the "perfect fifth"[1], that can be used as possible sources of data.

1 *"The Celestial Monochord elaborates on the discovery by Pythagoras of the ratios of harmony". "Fludd wrote, "what is this when compared with that deep and true music of the wise, whereby the proportions of natural things are investigated, the harmonical concord and the qualities of the whole world are revealed, by which also connected things are bound together, peace established between conflicting elements, and whereby each star is perpetually suspended in its appointed place by its weight and strength, and by the harmony of its lucent spirit"". Nichols, Kimberly (2013): Robert Fludd in the twilight of Renaissance, https://newtopia-magazine.wordpress.com/2013/07/19/thequeen-of-hearts-and-the-rosicrucian-dawn/, last view: 28.10.2018*

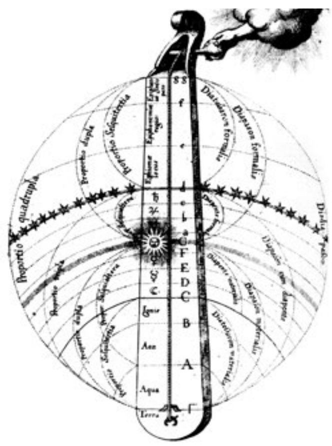
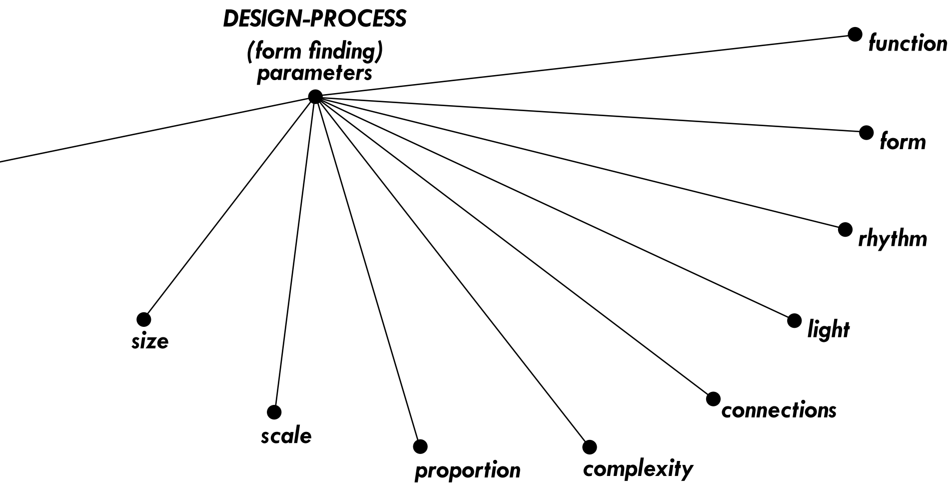


diagram R2
"The Mundane Monochord with its proportion and intervals"
De Musica Mundana, Robert Fludd, 1618



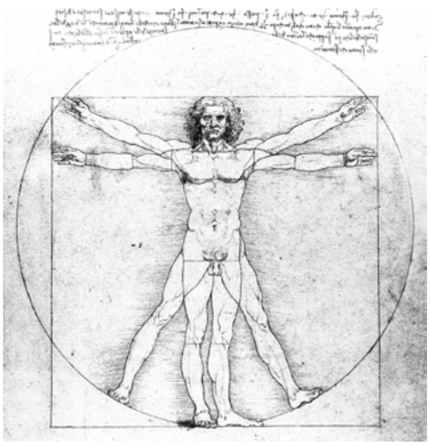


diagram R3
"Vitruvian Man"
Leonardo da Vinci, 1490

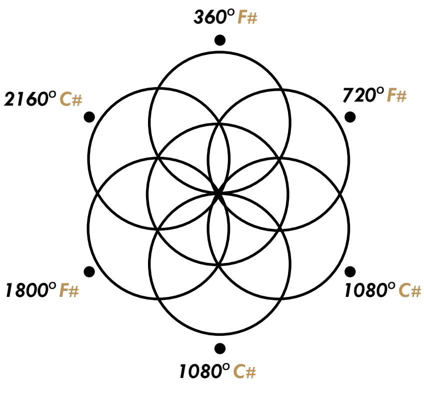


diagram R4
"sonic geometry 1.3"
Sonic Geometry: The Language of Frequency and Form, Eric Rankin 2013

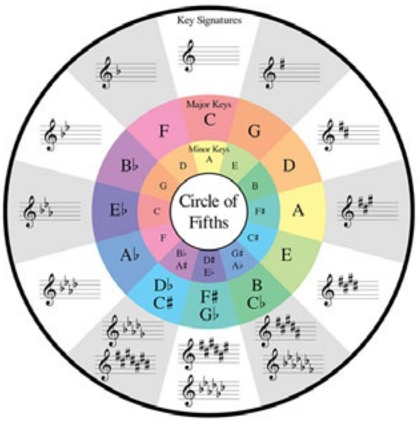


diagram R5
"Circle of Fifths"
Image by Sienna M. Wood, 2015

Photo R1
"Brandhorst Museum" Sauerbruch Hutton 2002

Photo R2
Berlin memorial to the murdered Jews of Europe, P. Eisenman, 1998-2005

Let's look at some examples of implementation (translation) of some particular parameters from music into architecture.

MUSICAL CHROMATICISM

On the *photo R1, and diagram R5* we can see an example of musical chromaticism translation in architecture.

"The stripes of colour are tilted in horizontal layers to deflect the road noise from the museum and muffle it, a clever invention that won the competition for the architects and, as a by-product, created the haunting set of joyful illusions that change with the distance of the observer. The sliding and shifting between visual chords here produces a literal version of musical chromaticism, the blending of colour overtones". Charles Jencks, 2013, "Architecture Becomes Music"

RHYTHM

Rhythm can be translated into architecture in many ways. One example is shown on *photo R2*.

In the Berlin memorial to the murdered Jews of Europe Peter Eisenman used staccato composition. In music, staccato is a form of articulation that means the notes needs to be played remarkably separated and distinct. In this project P. Eisenman used staccato pulse light/dark, A/B to send a message of presence/absence.[1].

1 *Charles Jencks (2013): Architecture Becomes Music*

Photo R3
FOUQUET'S BARRIÈRE HOTEL
Edouard François, 2004-2006, Paris

Photo R3 - another exemple of rhythm implementation in the design process. "*Edouard François, at the Hotel Fouquet, Paris, has been forced by building codes to adopt traditional elements, but he has transformed them into new syncopated rhythms. While the conservative arrondissement demanded a Haussmannian architecture of five storeys, the hotel management demanded an eight-storey structure with picture windows for tourists*". "*... the simple bay rhythm of A/b/A/b is emphasised by the superimposed blind windows on three floors, the top oeil de boeuf, and the repeated wall spaces between. So far so traditional, but then the expected steady beat – de-dum, de-dum, de-dum of melody 1, on the ground floor – is answered by the syncopation of the picture windows on the first floor. These are out of phase with the A/b rhythm, sliding across the b-bay creating a kind of de-dum (ti-slide) or glissando.*"

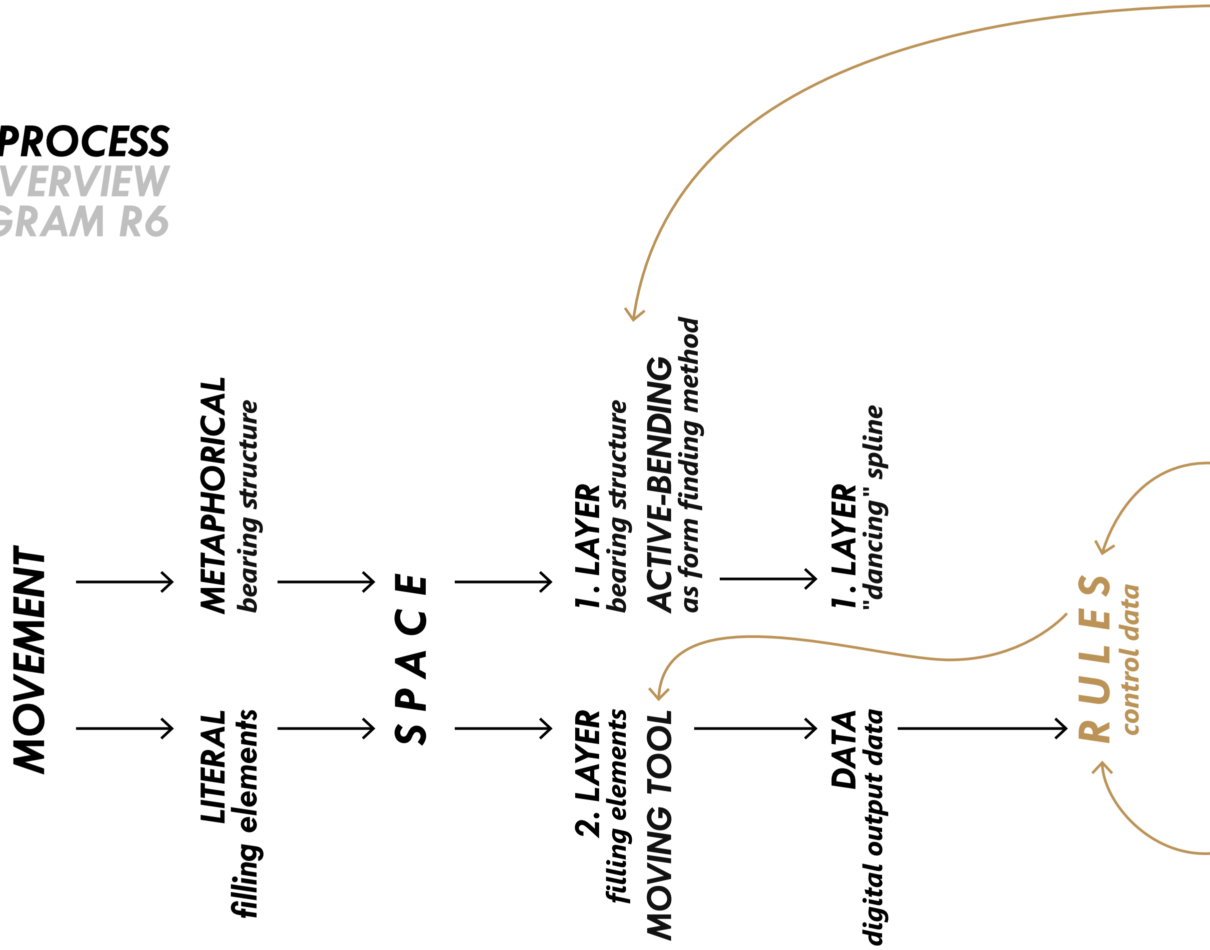
Charles Jencks, 2013,
"Architecture Becomes Music"

This approaches, as well as many others traditional approaches described in the previous sections in this book (mostly Introduction section) are examples of traditional work with music as a tool in architecture (parametrical architecture).

ARCOUSTICON is another type of musical-architectural projects. It is designed more like a musical instrument. Being an interactive and digital synthesizer, it needs another approach of real-time rules implementation for music generation, as well as visualization.

RU

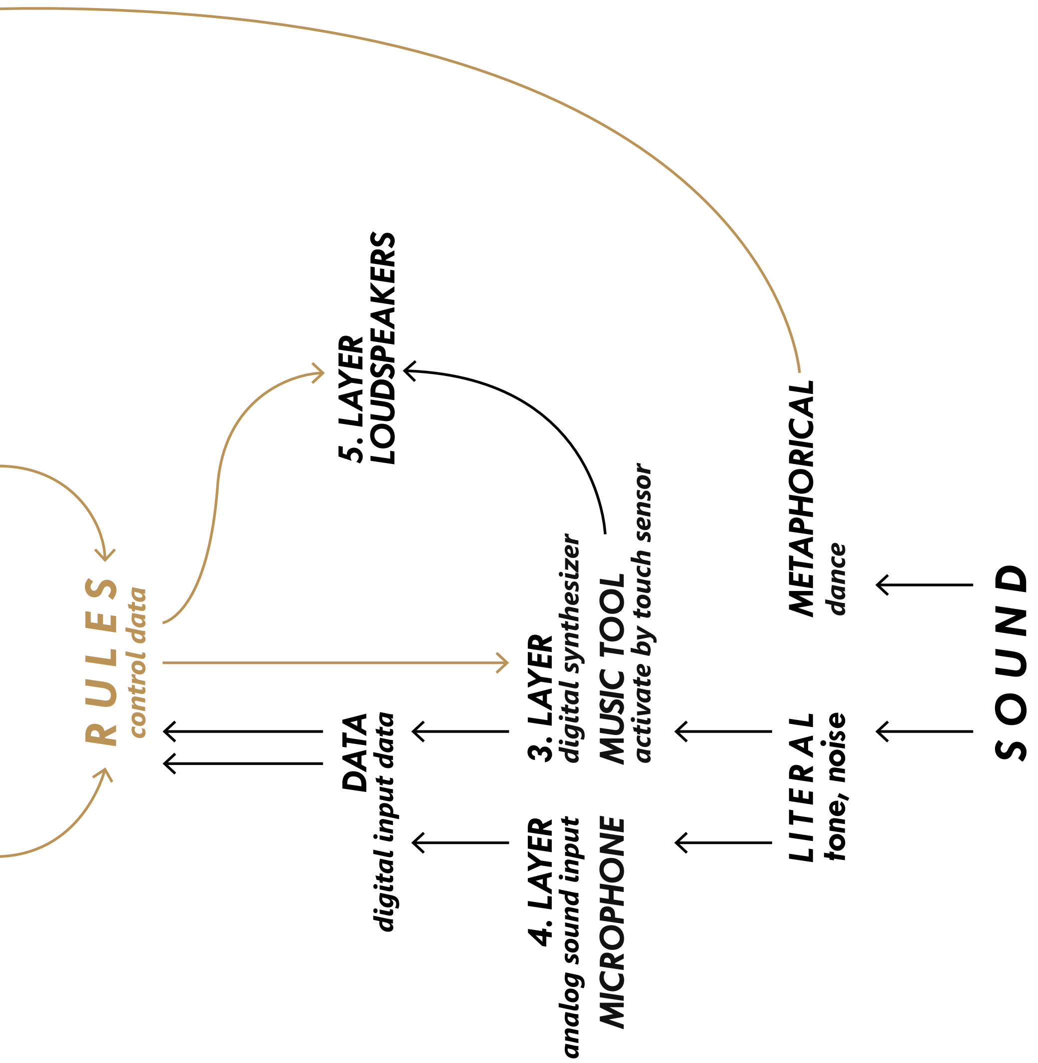
DESIGN PROCESS
CONCEPT OVERVIEW
DIAGRAM R6



As shown in the diagram above (final concept overview), the following components of the system are producing some data: 2. Layer- moving tools (sending positions of the motors); 3. Layer- musical tool (sending data from a touch sensor) and 4. Layer- microphone (send recorded surrounding sounds).

All this data type are different. To be usable in one control system they needed to be translated into one "language". For musical digital audio, such language is MIDI or musical digital interface. MIDI is "a technical standard that describes a communications protocol, digital interface, and electrical connectors that connect a wide variety of electronic musical instruments, computers, and related audio devices."[1] Developed software (Virtual MIDI loopback devise) receive and control all this data.

1 Wikipedia (last edited 2018): *MIDI*, https://en.wikipedia.org/wiki/MIDI, last view: 28.10.2018.



Data can be exchanged, transformed and sent to other devices (tools as a sound module, computer, drum machine, synthesizer) by using this device.

As shown in the diagram above, the following components need to get a back data: moving tools (new angle of rotation) as well as the musical tools (also need data exchange) and loudspeakers (gets an audio track to be played). On the next pages, the system of interaction between all of these components is described in more details.

R^U

RULES AND INTERACTIVE SYSTEM
RESEARCH

ARCOUSTICON, the space-creating musical synthesizer is designed as an interactive system.

This pavilion-instrument is able to read data from the environment input: sound (analog input, 4. layer of the structure) and tactile interaction of the human with the strings (digital input 3. layer of structure).

In this system, the data generated by the environment is a part of the musical tool (The upper part of the *diagram R6*). Following some rules (set by a software) data can be converted and transformed (as by typical digital synthesizer).

Lower part in diagram, describes the system of moving tool. Moving tool is responsible for new forms generation - visualization of sound in the real-time mode. Data generated from the any of two analog inputs can be used as for musical tool system, as well as for moving tool system.

The control system (Virtual MIDI loopback device) control the process of interconnection between musical and moving parts, input and output signals, its conversion from analog to digital and reverse, and the power source for 2,3,4,5 structural layers.

Which data will be used for each tool can be changed depending on the performance needs. As a digital synthesizer, Arcousticon offers several modes possibilities and connection to application software for music generation, as for example Ableton Live.
The rules (programs) allows real-time interaction between sound, form and of course human.

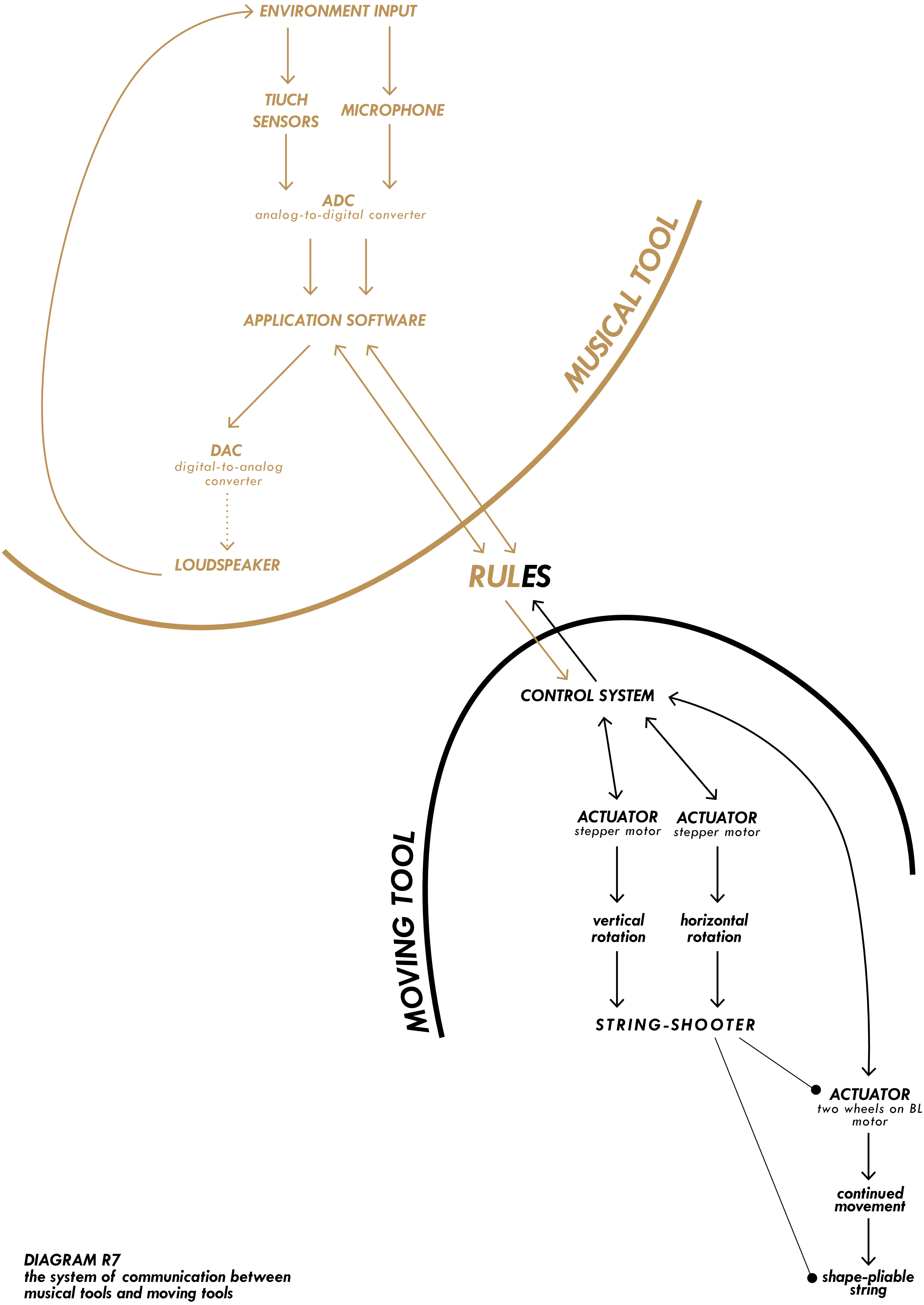
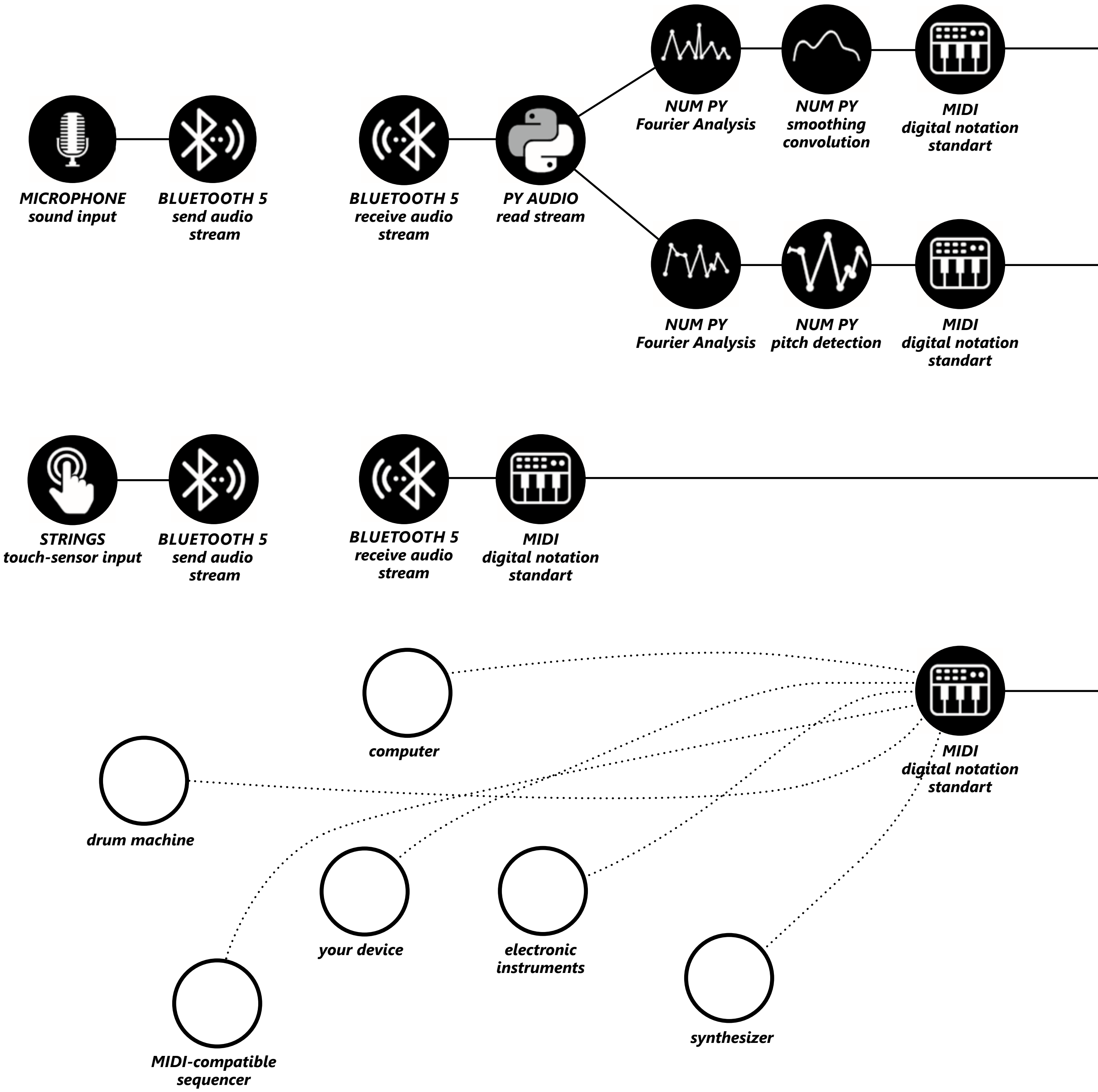
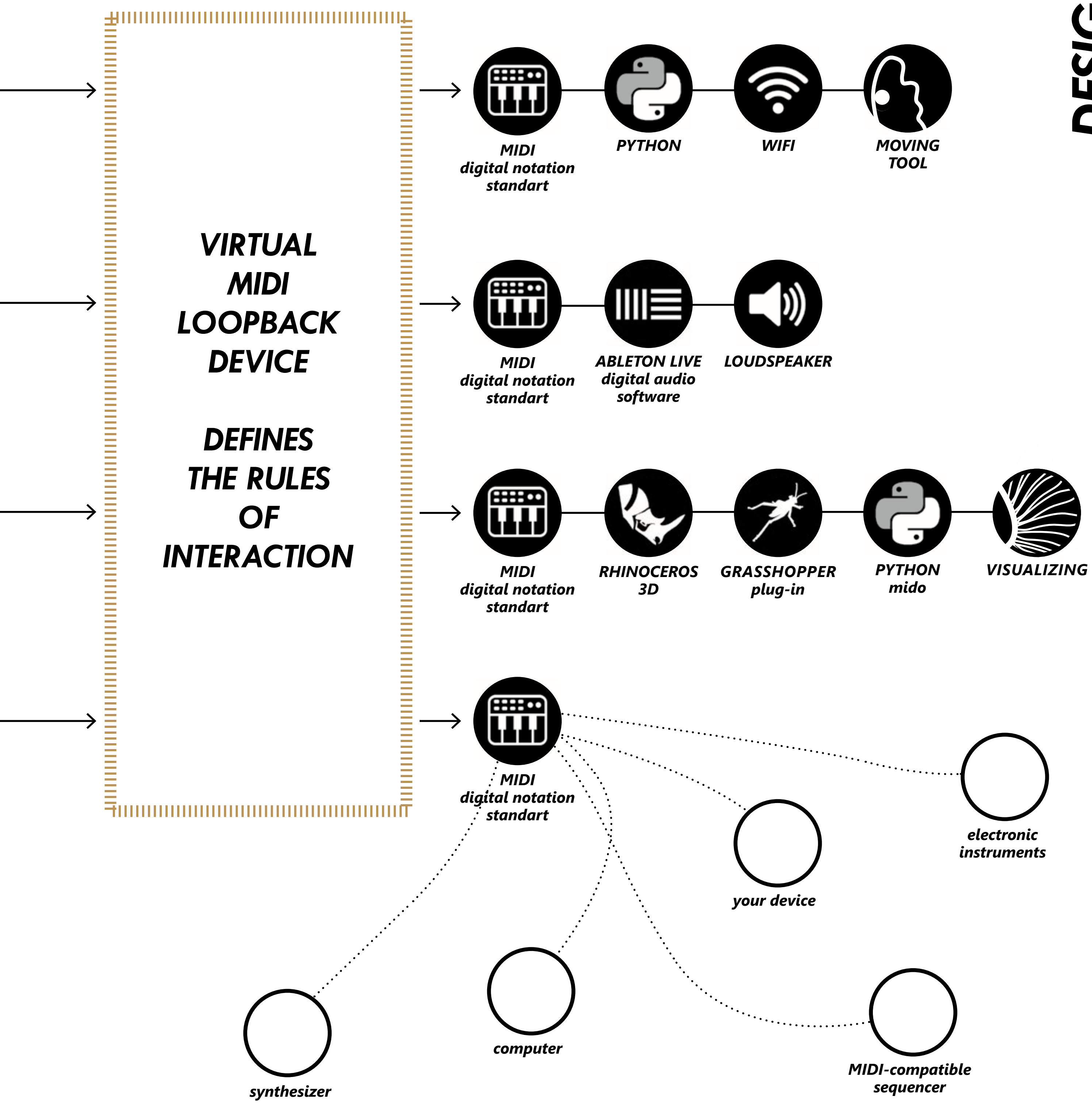


DIAGRAM R7
the system of communication between musical tools and moving tools

THE SYSTEM OF DATA EXCHANGE ARCOUSTICON

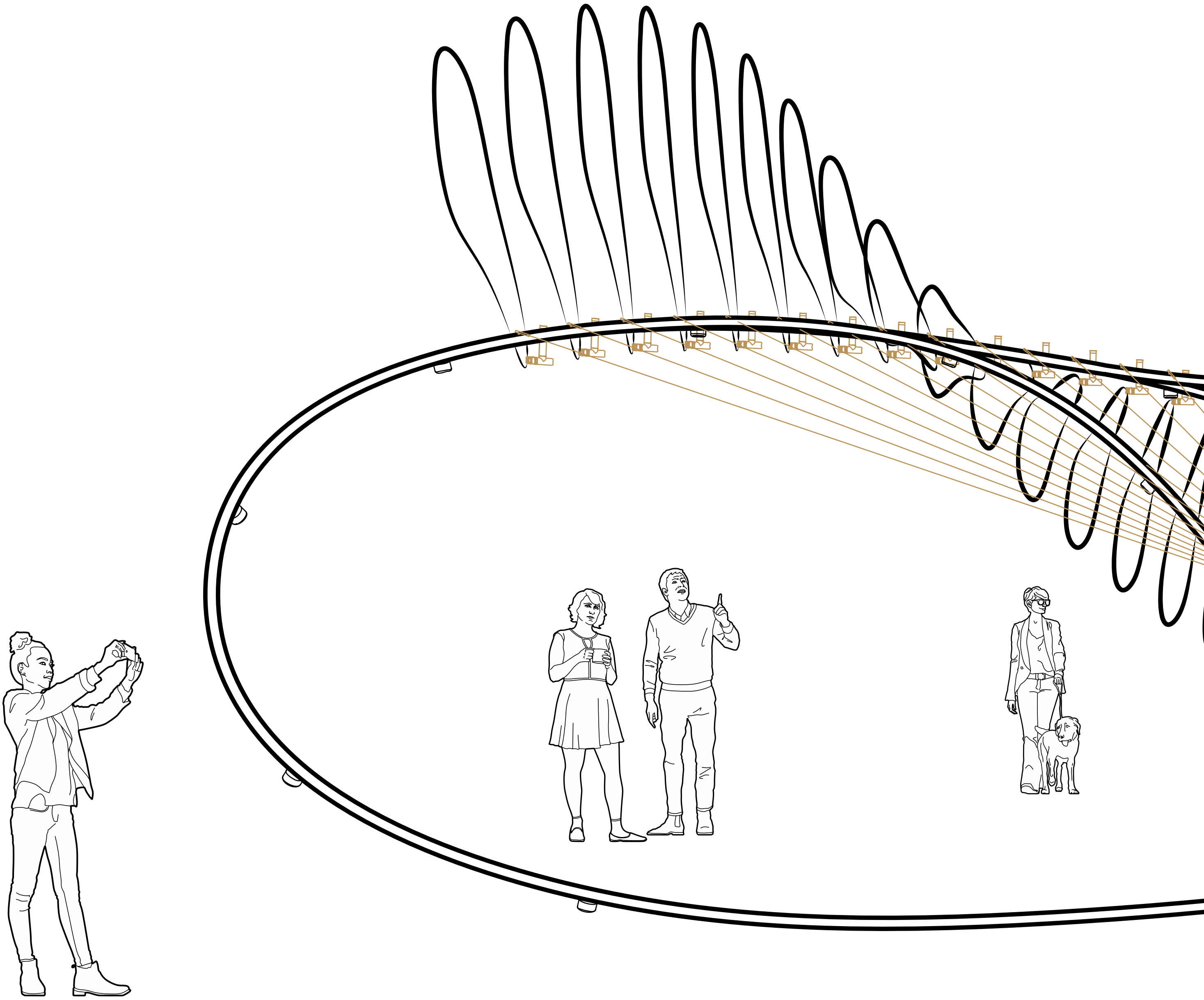
DIAGRAM R8
DETAIL,
VIRTUAL MIDI LOOPBACK DEVICE



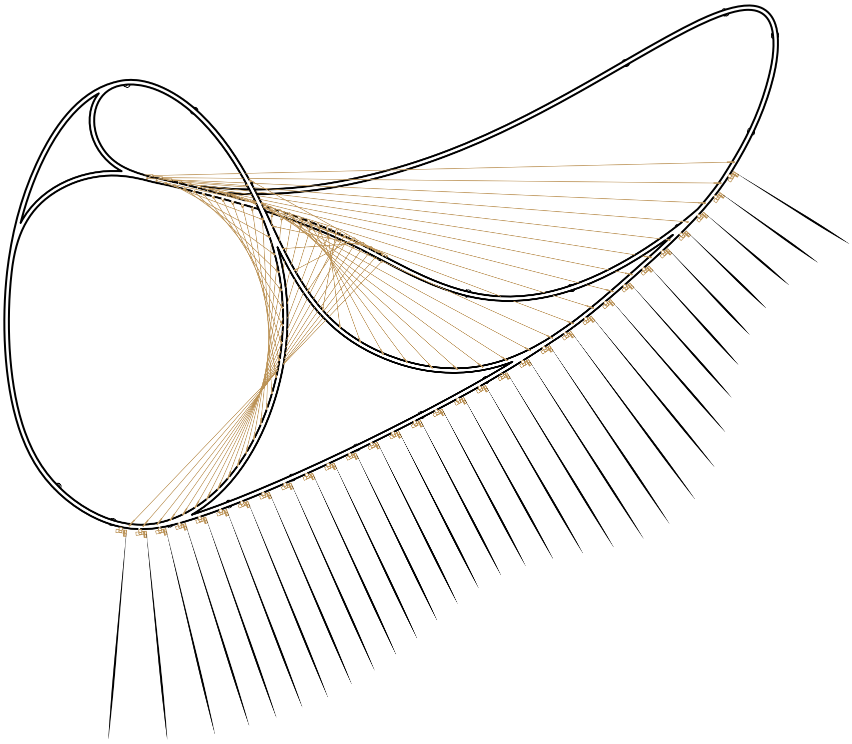

VIRTUAL MIDI LOOPBACK DEVICE
DEFINES THE RULES OF INTERACTION
MIDI digital notation standart
PYTHON
WIFI
MOVING TOOL
MIDI digital notation standart
ABLETON LIVE digital audio software
LOUDSPEAKER
MIDI digital notation standart
RHINOCEROS 3D
GRASSHOPPER plug-in
PYTHON mido
VISUALIZING
MIDI digital notation standart
electronic instruments
your device
synthesizer
computer
MIDI-compatible sequencer

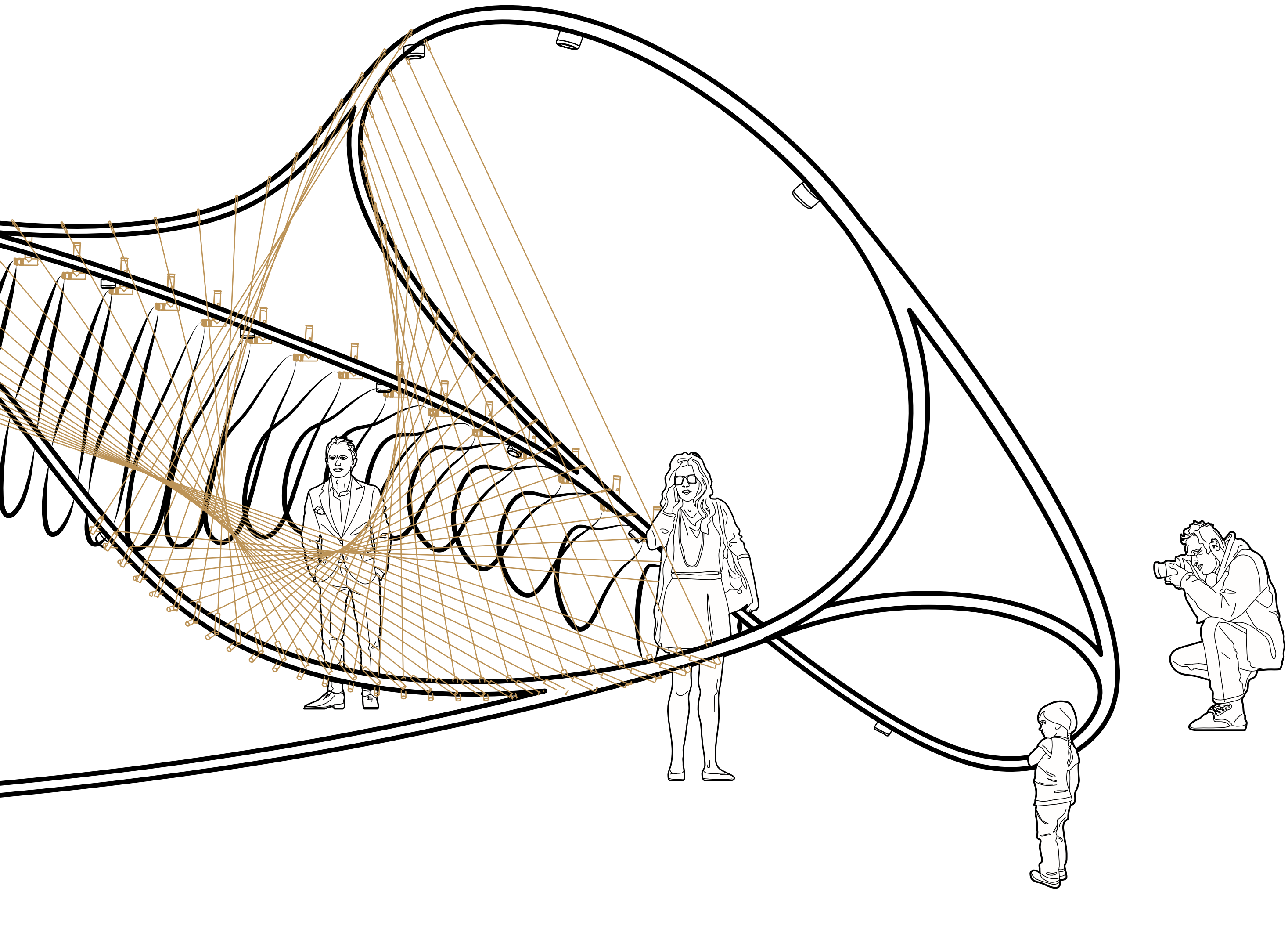
1.LAYER
BEARING STRUCTURE
+
2.LAYER
MOVING TOOLS
PERSPECTIVE VIEW
+
3.LAYER
MUSICAL TOOLS
PERSPECTIVE VIEW

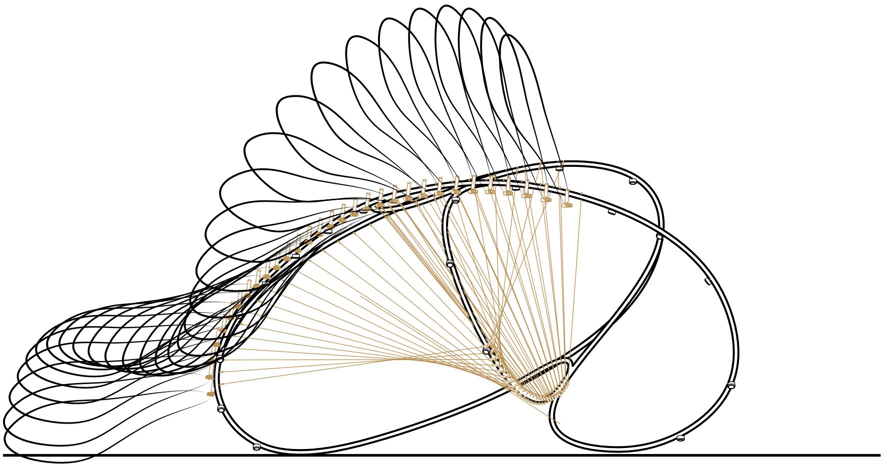
DRAWING R1



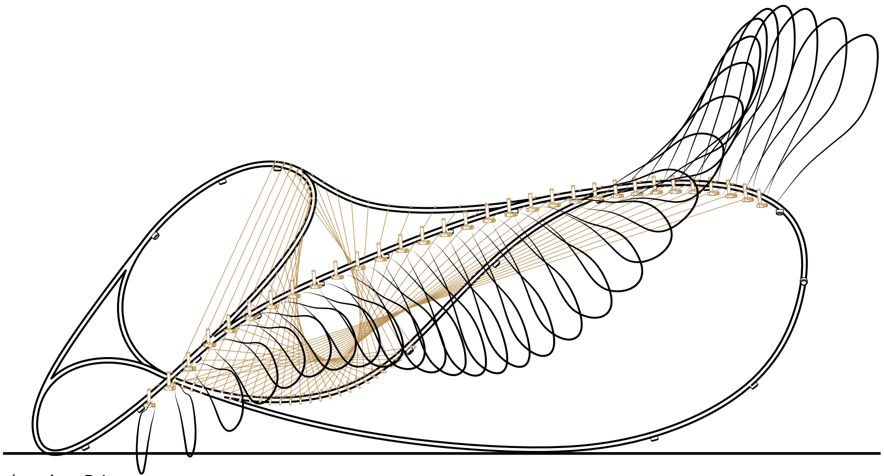
drawing R2
Top View, *M=1:100*



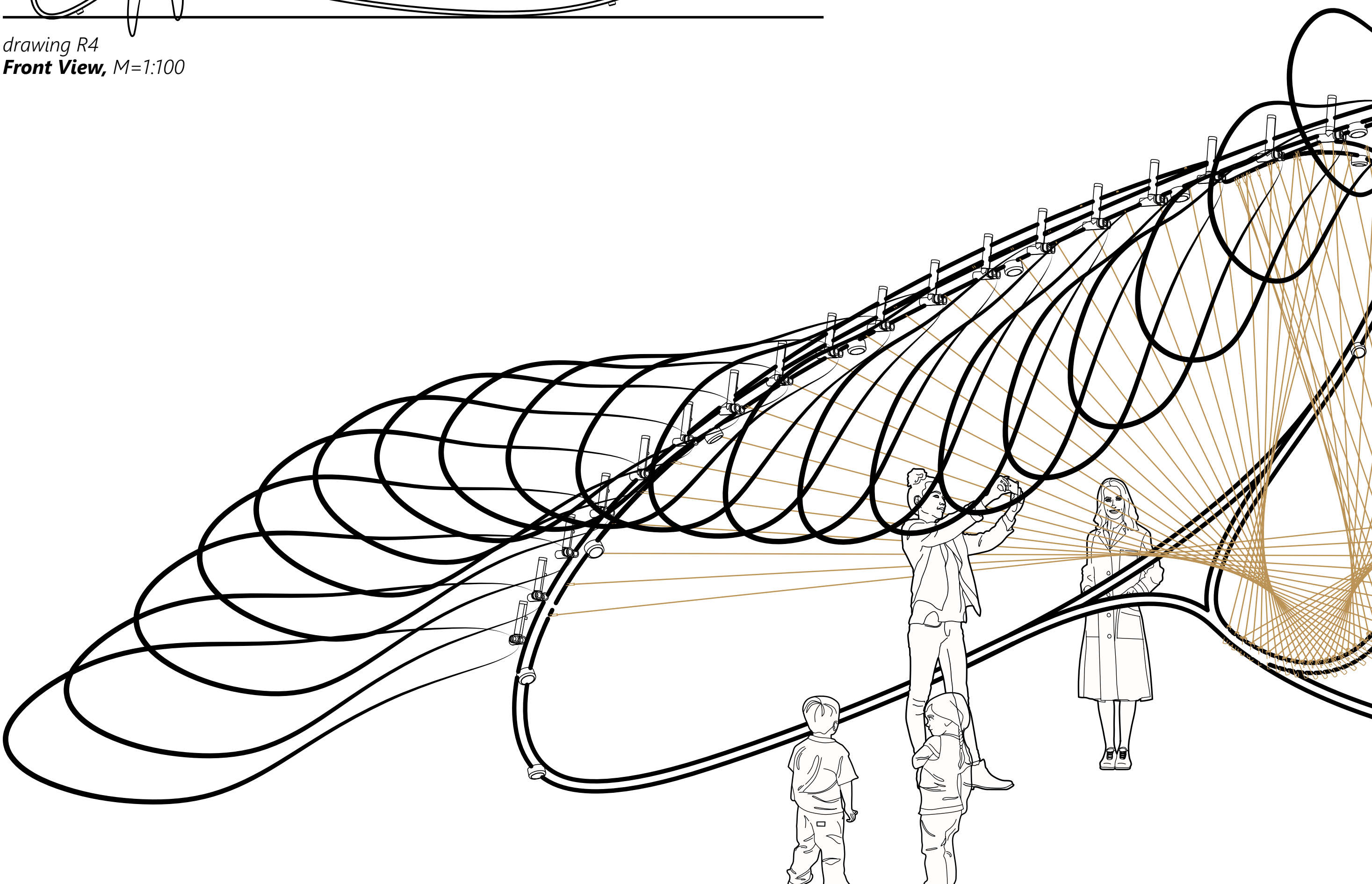




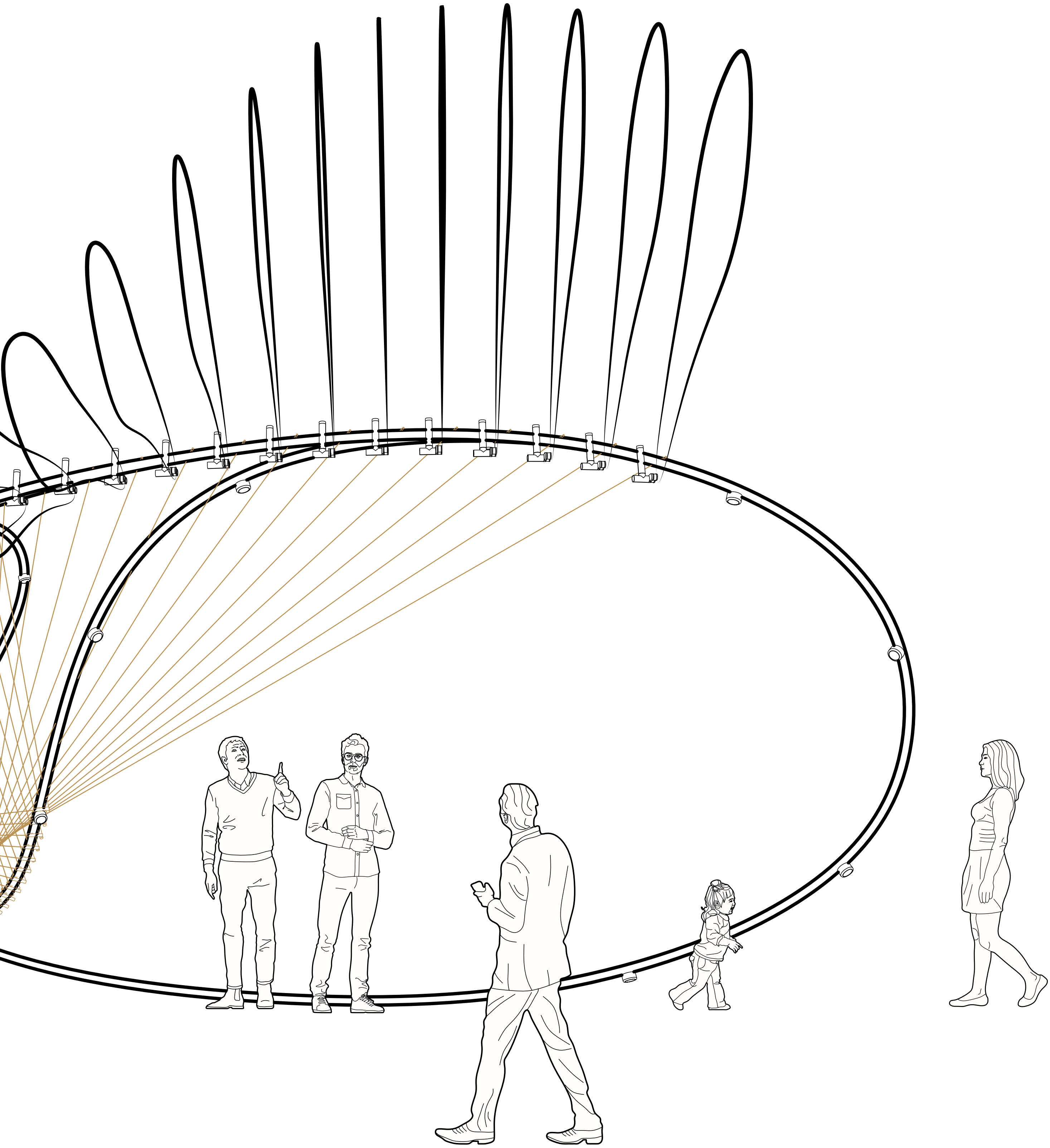
drawing R3
Side View, *M=1:100*



drawing R4
Front View, *M=1:100*

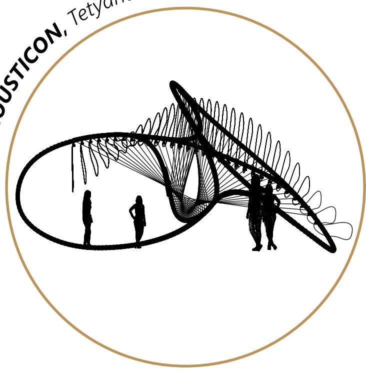


PERSPECTIVE VIEW
DRAWING R5



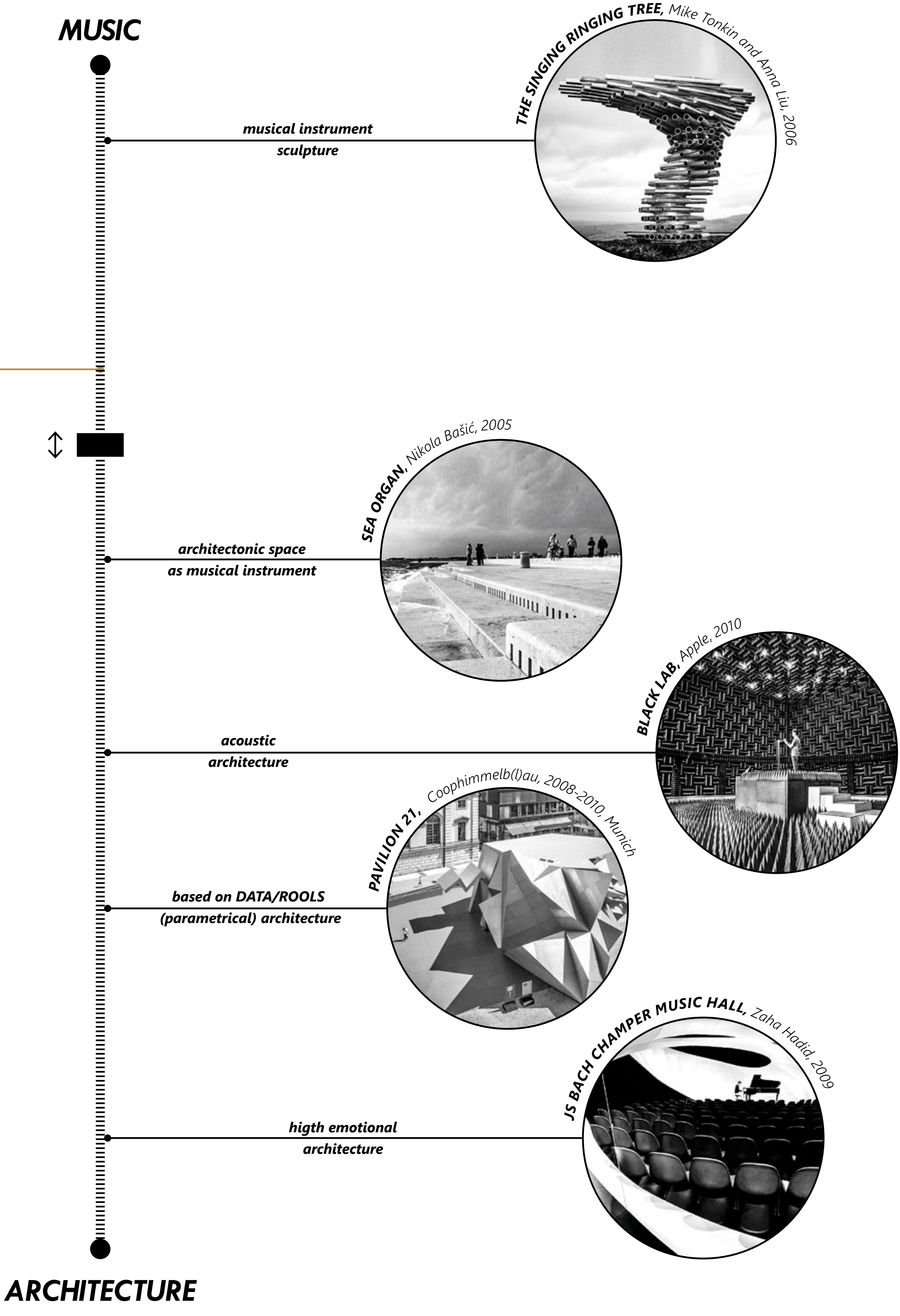
ARCOUSTICON

ARCOUSTICON, *Tetyana Vovk, 2018*



musical instrument

interactive space generator


MUSIC
THE SINGING RINGING TREE, Mike Tonkin and Anna Liu, 2006
musical instrument
sculpture
SEA ORGAN, Nikola Bašić, 2005
architectonic space
as musical instrument
BLACK LAB, Apple, 2010
acoustic
architecture
PAVILION 21, Coophimmelb(l)au, 2008-2010, Munich
based on DATA/ROOLS
(parametrical) architecture
JS BACH CHAMPER MUSIC HALL, Zaha Hadid, 2009
higth emotional
architecture
ARCHITECTURE

CONCLUSION

GENERAL

The objective of this diploma was to provide a ***GENERAL INSIGHT*** into possible vectors in the design process by working on the cross-section of architecture and music.

For this purpose, there was developed an approach that considers the connection between architecture and music as a product of different ***INTERCONNECTIONS BETWEEN THEIR PARTS***: movement, space, sound, and rules.

Let's imagine a sliding scale where, on one end, are architectural projects with a very minimal inclusion of musical parameters. On the contrary, on the other end of the scale is placed the musical sculpture that minimally outlines the space. Between these two starting points, architectural-musical projects that are described in this paper can be found. (Diagram xx on previouse page)

Depending which way on the scale we are moving, the importance and the need for different components (***MOVEMENT, SPACE, SOUND, RULES***) and their parameters will be changing.

Within the framework of this diploma, a system of interconnections between these parameters has been developed in order to answer the question:

What happens if we try to ***"UNFREEZE"*** the music, and let the architecture move?

The result of this search led me to the design of ***ARCOUSTICON***, an interactive digital MIDI instrument (synthesizer) that not only generates music, but also changes its shape through the moving elements.

This ***SPACE-CREATED INSTRUMENT*** is something more than a typical musical instrument or musical sculpture, such as *"The Singing Singing Tree"* project. At the same time, it does not have a specific architectural function, such as musical pier project "*Sea Organ*". Arsousticon is somewhere in the middle, and therefore on the scale is located between these two architectural-musical and musical-architectural projects.

The rules and types of interaction in the developed instrument may vary depending on the purpose of a particular performance. The control system is designed as a ***VIRTUAL MIDI LOOP DEVICE***, that allows various components to interact with each other in different ways.

TACTILE or ***AUDIO*** signals not only can generate music (as is usually the case with typical digital music synthesizers) but also bring moving elements into motion.

Arcousticon is an interactive space based on the interconnection between ***HUMAN***, ***MUSIC***, and ***FORM***. A peculiar place for musical and spatial experiments in real time mode.

Moreover, it can serve as a foundation for future applications and exciting projects. The monitoring system designed in this project (virtual MIDI Loop control device), allows you to connect ***OTHER MIDI DEVICES*** to Arcousticon, thus expanding the range of possible interactions and functions.

Therefore enables interaction between human, sound, form and your own MIDI tool.

VALUE

This work can serve as a reference model for the development of interactive architecture-musical spaces.

The moving tools, as well as music tools prototypes, are lit from the perspective of their implementation in architecture.

The findings in tools construction, form-finding process, material selection, control, and simulation can be elaborated and transferable to the exploration of other systems in other projects (interactive musical facades, musical walls, a kinetic architecture based on a MIDI interface are a few of various possibilities).

„...DREAM ON, DREAM ON, DREAM ON, DREAM UNTIL YOUR DREAM COMES TRUE...“,

Dream On, Aerosmith 1973

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