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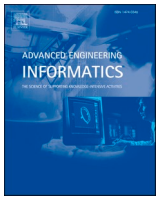

Full length article

Taxonomy for building permit system - organizing knowledge for building permit digitalization

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ABSTRACT

The building permit process is a crucial aspect of the construction industry, as it ensures the safety and compliance of buildings with local regulations. A significant improvement in terms of accuracy, transparency and efficiency would be brought from digitalization, therefore several projects are being developed on the topic. However, to reach high maturity levels, it is necessary to address the several parts of building permit systems in a structured way, by considering the several subsystems composing the main issue thoroughly (e.g., legislative, organizational, technological, procedural). Therefore, this article proposes a taxonomy of building permit systems that can be the reference to guide and assess related developments across diverse countries, allowing their interpretation in a common framework. Different methodologies for taxonomy developments were applied in this study, including a combination of committee approaches and empirical methods, with a final validation against a use case. The obtained high-level taxonomy of building permit systems can serve as a basis for future improvements in the building permit digitalization and could be the basis for an extended ontology.

1. Introduction

Building permitting plays an important role in the construction industry. It constitutes the act of authority of the local administration based on the application of the measures laid down by law relating to siting, design execution and operation of construction. It aims to secure the safety, sustainability and compliance of buildings with the local regulations.

Current building permit systems, still mostly based on analogue documents and processes, have limitations that hinder their efficiency and transparency [1]. Digitalization, which includes using digital data as input and output and digital tools to support or automate checking, has the potential to address

these challenges and improve the process [2,3]. Despite the potential benefits of digitalization, and the significant digital transformation of the AEC domain, the building permitting process remains a challenging goal. As the permitting system relies on stakeholders from different sectors, including the public sector, and involves governance aspects, the challenge of a digital transformation goes well beyond the development of tools for digital delivery [4]. A basis for adoption and implementation of the developed tools in the different sectors becomes vital [5]. To support a digital transformation in the building permitting domain, a basis of knowledge needs to be established which includes not only the technological aspects to support industry in development of the technological infrastructure, but also the involved procedures, legislation on different levels and the involvement of various organizations.

As part of a study which is being developed by a working group in the European Network for Digital Building Permits (EUnet4DBP) [6], a large dataset was collected through qualitative expert interviews to document the current status of building permit systems across Europe, with the

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objective to investigate the current building permit processes in different countries, compare them with each other, and derive lessons-learned. During the analysis of the dataset, the need emerged to have a reference framework to interpret and categorize each part of the information, and to clearly identify which parts of the building permit system are discussed. The requirement for clarity becomes more and more important in building permitting since we are just at the beginning of understanding its complexity.

In fact, a building permit system is comprised of the combination of several subsystems, which are needed to tackle the diverse issues implied. Several disciplines are involved and for each part of the challenge it is necessary to consider specific issues from the relevant points of view, such as the technology implied, the organizational aspects, how human operators interact among each other, what are their skills, how political decisions influence the process, what kinds of regulations are used, and so on.

Addressing all these parts may lead to a successful digitalization of building permits. A structured approach is necessary both to understand and assess the status and maturity of building permits for a considered building authority at a certain moment and to support the development of a roadmap towards higher levels of digitalization.

Several projects and initiatives intended to digitalize building permits have considered only some parts of the issue, focusing on some specific aspect (e.g., the process, the regulations' text [7], the checking tools [8]) or on the overall challenge, especially in the practical cases of building authorities willing to switch their systems to digital building permits. However, a shared framework within which to categorize each effort or solution is currently missing. This makes the task harder to compare different building permit systems and solutions. For this reason, this study was developed in order to provide a high-level taxonomy of the different issues and subsystems involved in the building permit system.

The objective of the presented taxonomy is not to provide a comprehensive vocabulary or ontology of all the building permits terms, but provide the highest-level categories, explained with examples, in order to allow consistency in interpretation and comparison of different initiatives and support effective digitalization.

1.1. The theory of systems

The theory of systems can support the definition of the comprehensive building permit system, and it represents a useful starting point. The field of civil engineering and architecture involves complex issues that are difficult to represent in a straightforward manner. These issues are characterized by multiple interconnected problems and their relationships with various aspects, making it difficult to simplify them. To understand such issues, they are conceptualized as systems and represented through models, which can capture all the relevant connections, although they focus on the necessary ones rather than exploring every possible association exhaustively. The main goal is to comprehend the overall nature of a problem, rather than considering isolated sub-areas separately. As a result, a certain level of abstraction is used, creating abstract systems representations that are aligned with specific problem contexts or solution approaches. Defining the abstract systems facilitates problem-oriented analysis [9].

The identification of a system depends on both its problem and its intended purpose. Moreover, the level of scrutiny applied to the system is influenced by its desired objective. The characteristics of the system play a role in describing it, although a complete understanding is not always attainable [10]. To make it easier to understand complex constructs and present important information clearly, various methods can be used. These methods include breaking down the construct into smaller parts (decomposition), organizing it into a hierarchical structure, or defining operational processes. As a result, subsystems are created as components of a larger system [11,12].

Models play a vital role in understanding and improving the clarity and communication of complex systems. From a scientific perspective, a model can be described as an object or structure that visually represents the internal relationships and operations of a phenomenon. Models use simplified or idealized representations to depict the complexities of reality, sometimes employing schematic diagrams, and adhere to the principle of abstraction [13,14,15].

The building permit process and its digitalization is a highly complex issue as well, for example due its multi-disciplinarity. We see a lot of interconnected aspects and problems difficult to represent straight forwardly. We also recognized that experts in the field are focused on specific sub-areas, not necessarily able to comprehend or represent the entire picture.

1.2. Background on taxonomies

Proper organization and structure of knowledge is essential to any field of study, as it improves common understanding and facilitates progress by allowing for broader application of research findings, products and solutions. The science of classification and categorization is called 'taxonomy', which involves identifying and defining concepts, organizing them based on their characteristics, similarities, or differences, and creating a specific system for knowledge organization. According to Nickerson [16], taxonomies refer to both (1) the discipline studying the classification criteria of a given set of items and (2) a specific classification system of knowledge organization [17]. When designing a taxonomy, certain qualitative properties must be considered, such as: completeness, comprehensiveness, mutual exclusivity, unambiguity, and usefulness [18]. 'Completeness' means that the taxonomy covers a whole target domain without gaps. 'Comprehensiveness' depends on the detail and depth of the taxonomy. 'Mutual exclusivity' means that the concepts should not semantically overlap. 'Unambiguity' implies that the concepts should be exhaustively and specifically explained. Finally, the taxonomy should prove its 'usefulness' for real world use cases.

There are two types of taxonomies: hierarchical and faceted. The former is a traditional type, while the latter is used when the information in the domain is multi-dimensional. The most renowned hierarchical taxonomy originates from evolutionary biology and is used to classify the organisms based on shared characteristics (kingdom, phylum or division, class, order, family, genus, and species). The arrangement of terms is established through parent–child relationships. If the information in the domain is multi-dimensional, the taxonomy should be designed as a faceted taxonomy which consists of more than one hierarchy, each of which are called "facets". Each facet represents a separate context or topic of the information. This type of the taxonomy is also known as horizontal taxonomy. An example of such taxonomy for clothes are color, material, function, and pattern facets [19]. Each individual facet can have a hierarchical parent–child structure of terms.

1.3. Existing thesauri, taxonomies, vocabularies and glossaries

In the architecture, engineering, and construction (AEC) industry, taxonomies are used to classify and organize building components, systems, and materials based on their properties, functions, and relationships. Taxonomies aid in enhancing communication and collaboration among diverse stakeholders in the AEC field, as well as in the geospatial communities and software industry.

The digital building permit use case is by nature extremely multi-disciplinary: regulatory experts, city planners, building designers, construction companies, geoinformation experts, building information models experts, software developers and more need to collaborate in order to achieve effective results. Therefore, a taxonomy for building permit necessarily relates to several domains, which are in turn represented in schemas with different levels of complexity, including vocabularies and taxonomies.

The AEC field is rapidly evolving in terms of digitalization with

Building Information Modeling (BIM) being the leading technology. The increased complexity of digital data and digitally supported processes led to an even higher need for collaboration and especially mutual understanding. Farghaly *et. al* [20] developed a taxonomy for BIM and asset management to foster the interoperability between the two. Klein et al. [21] investigated the factors that hinder the adoption of BIM and developed the taxonomy to aid the identification of the resistance to change. However, they are only relevant to classifying a small part of the information involved in building permits.

The ISO 16739–1 buildingSMART IFC schema [22] offer a schema for the life cycle of the built environment, spanning spatial, physical and process aspects. The process model represents work-plans (packages), task types (method statements) and individual tasks. Relationships are available to model task precedencies, and properties can represent planned and intended dates. Whilst most implementations have used this aspect to represent the construction stage, the adoption of ISO19650 [23] has increased interest in modelling the design engineering, information development and approval processes. Many regulations impose requirements on the process of design, application and construction, for example the delivery of information packs to the owner before occupation. The spatial and physical aspects of the schema including zones, systems, spaces and components are particularly relevant to building permitting as most regulations focus on the final form and use of the building. The three main aspects of the schema are supported by resources, including a constraint sub-schema. The constraint resource includes metrics which are statements that can be tested against the building model, and objectives which are defined by the logical combination of metrics and other objectives. This has been used to communicate US building codes to Solibri [24] and other rule engines in the SmartCodes project [25] which used the RASE markup [25] to expose the logical ontology and metrics embedded in existing regulatory documents. New regulatory and requirement documents can use the same logical ontology by adopting ISO12911 [26].

The IFC is supported and extended by the ISO and buildingSmart data dictionary (bsDD) [27] which hosts concepts with definitions in multiple contexts, such as natural languages, IFC usage, classification tables and other third-party content. Both the IFC and the bsDD are available as semantic web resources.

Omniclass [28] in the US and Uniclass [29] in the UK offer a suite of classification tables conformant to ISO12006-2 [30]. ISO 81346 [31] extends this standard with specific coding patterns which have been adapted in several European implementations such as CoClass [32] in Sweden and CCS [33] in Denmark. ISO12006-2 [30] expects separate classification tables for recognizable entities including spaces such as stairways, built elements such as doors and entities such as buildings. There are also tables for aggregations including built complexes such as campus and systems such as ventilation. Both entities and aggregations are the subject of regulatory controls. The ISO 6707–1:2020 Buildings and civil engineering works –Vocabulary – Part 1: General terms [34] is an additional reference, being available in multiple languages.

For geospatial information science, the OGC Glossary, which is structured in the OGC 'Registry for Accessible Identifiers of Names and Basic Ontologies for the Web' (RAINBOW) [35] and the ISO/TC 211 Multi-Lingual Glossary of Terms [36] are the references from the international standardization organizations in the field. The OGC Rainbow, in turn, refers to external vocabularies as well. For example, the 'Cadastre and Land Administration Thesaurus' [37] is already referred within the OGC Rainbow and can be a relevant reference for many aspects related to digital building permits, including the legal aspects related to the zoning plans and the organizational or societal terms (CaLAThe 'Party'). CaLAThe is in turn referring to more resources, some of which will be considered in this paper also for reference to other parts of the descriptions. For example, the 'feature concept dictionary' [38], 'glossary' [39] and 'theme register' [40] provided within the European Directive for an Infrastructure of Spatial Information in Europe (INSPIRE) [41] report meaningful definitions and structures.

Another relevant field in building permit system, for which taxonomies and classification systems are available is software development.

The Open Group Architecture Framework (TOGAF) provide a foundational architecture including a technical reference model, i.e., a taxonomy of generic platform services, and a standards information base, i.e., a database of useful standards to define services and components [42]. Moreover, the European Interoperability Reference Architecture (EIRA) ontology [43] provide the classification of concepts regarding the metamodel defining the building blocks for interoperable e-Government systems.

Additional taxonomies related to further domain exists, such as for legal theory [44]. or organisational aspects [45]. However, a higher-level glue for the overall system had never been defined.

In order to make the taxonomy for building permit systems mostly reusable, understandable and interoperable, relevant existing sources will be considered every time in which it would be possible. Table 1 summarizes the scope for relevant thesauri, taxonomies, vocabularies and glossaries.

2. Methodology

We emphasize on qualitative research methods to comprehensively identify and explicate the highest-level categories in these initiatives, and thereby enhance the understanding of the building permit systems through a taxonomy. Our approach aims to further enrich the qualitative narrative by providing contextualized examples, of the taxonomy for building permit use-case. The methodology of this study is divided in five steps as can be seen in Fig. 1. The steps are named: Committee 1 approach (step 1.1), Empirical approach (step 1.2), Committee 2 approach (step 2), Result representation (step 3), and Use case verification (step 4).

There are three main approaches to designing a taxonomy, including the inductive, deductive, and intuitive approaches, and the taxonomy design can be a mix of these methods. Inductive approach is based on the

Table 1
Relevant existing thesauri, taxonomies, vocabularies and glossaries overview, related to AEC (orange), geospatial information and land management (blue) and software components (yellow).

Taxonomy	Scope
ISO 19,650	Information management processes for built assets
ISO 16,739 IFC and bsDD	Built asset schema and multi-lingual and multi-domain terms compliant to ISO12006-3
ISO 12,911	Structures for normative requirements for information management implementation using RASE.
Omniclass (US) Uniclass (UK)	Spatial, physical and process aspects of built assets to ISO12006-2
CoClass (Sweden) CCS (Denmark)	Spatial, physical and process aspects of built assets to ISO81346-12, which extends ISO12006-2
ISO 6707–1:2020 Buildings and civil engineering works –Vocabulary – Part 1: General terms	General concepts for building and civil engineering works
OGC Glossary ISO/TC 211 Multi-Lingual Glossary of Terms	Geospatial information related terms definitions
Cadastre and Land Administration Thesaurus (CaLAThe)	Cadastral and land administration-related concepts
INSPIRE	Land representation, administration and environmental related topics (such as addresses, administrative units, cadastral parcels, and coordinate reference systems)
TOGAF technical reference model	Platform services and software components
EIRA ontology	Building blocks for e-Government systems

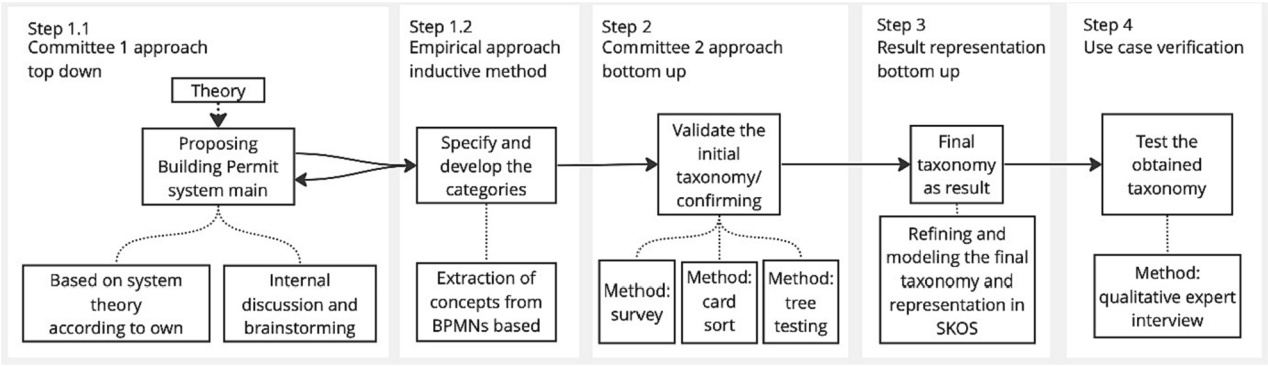

Fig. 1. Methodology Workflow.

analysis of concrete examples and situations, which serve as a basis for taxonomy creation. This bottom-up method begins with observation and progresses towards theory. The deductive approach is inverse. It is guided by a conceptual framework, with the taxonomy being constructed based on preconceived theoretical concepts. Lastly, the intuitive approach lacks a prescribed methodology and is instead based on the designer's individual perception and understanding of the domain [16].

The standard (ANSI/NISO Z39.19–2005) (R2010) [46] defines three main approaches: the committee approach, led by a group of experts in the domain; the empirical approach, in which the starting point to select and interpret the terms are content objects; machine assistance, in which software tools may be used to assist in the identification and analysis of terms. A combination of methods is often used and foreseen by the standard as well. It would allow the critical assessment of the taxonomy with different points of views and approaches, making it more robust. For this reason, this is the method chosen in this study. To define the taxonomy, a combination of the taxonomy construction methods proposed in the standard ANSI/NISO Z39.19–2005 is used [46].

Two committees (step 1.1 and step 2) are involved to facilitate the committee approach part. The first committee (Committee 1) involved in the definition of categories and relevant terms is the group of authors. All of them have substantial experience with dealing with building permits digitalization in research and practice. They are all currently involved in relevant projects on digital building permits and are very active in the European Network for Digital Building Permit [6]. For Committee 1, we base on a common sample size of a focus group which is up to 8 experts [47 48].

The second committee (Committee 2) is composed of a group of experts involved in a workshop within one of the EUnet4DBP meetings, plus other experts and colleagues invited by the authors. For both the groups the internal diversity was essential, in terms of field of expertise (architecture, geospatial science, civil engineering, project management, computer science in construction, etc.), working sector, and geographical location. It is important to note that this is not quantitative research. Hence, we are not looking for a statistical analysis based on a large set of responses. Our main approach is qualitative, in-depth analysis that is performed by purposeful sampling, namely the population is limited to people who have prior knowledge in the domain [49]. As such, we are not looking for large data sets, any number of high-quality responses greater than 10 would be sufficient [50]. This may not achieve maximum variation but will be sufficient to discover the common ground and understanding of the concepts in the permitting domain. For a qualitative study it is recognized that only a limited sample size is needed. The quality of the respondents and the collection of the experts is more important [49], and it has been found that sample sizes of usability of such studies is highly limited and very few new characteristics is found after seven [51].

2.1. Step 1 – The first taxonomy draft

As a first step the Committee 1 (step 1.1) proposed the main categories of the taxonomy, after reviewing the relevant literature on systems description (see Section 1.1) and based on groups' own experience. This initial draft was analysed and discussed internally, in order to find an initial agreement within the Committee (Committee approach – top down). In addition, in a workshop and brainstorming session, additional terms and examples were added to the initial high-level categories, together with the proposal of definitions of the categories and concepts added.

A following step to further check the completeness of the initial proposal was done by systematically extracting terms from Business Process Modeling and Notation (BPMN) maps of building permit processes. Although this could have been achieved manually, we exploited the fact that BPMN is an XML-based format. A simple XML transformation (XSLT) sorted and reported all text found on the actor swimlanes, process boxes and information-flow arrows. In addition, any informal annotation was also listed. An actor swimlane is a visual element that groups and categorizes activities or tasks in a process diagram, typically based on the roles or departments responsible for carrying out those tasks.

The BPMN maps were created based on interview data as explained in section 1 (Empirical approach – inductive method). The BPMN maps were randomly chosen, 5 maps from 5 different European countries. The BPMN maps represent the building permit process in the respective country, mainly focused on the authorities' perspective. The intermediate result was in turn assessed and discussed internally.

For better understanding of the word usage, Fig. 2 shows a schematic overview of the used terms regarding the taxonomy structure. It needs to be noted, that concepts include a definition, instances are additionally given to the concepts for better explanation.

2.2. Step 2 – Enhancing the level of agreement and common understanding

Step 2 of the methodology is intended to validate and improve the initial proposal.

A second committee approach was adopted, involving the Committee 2 with three main exercises: a survey through a web form to validate the completeness of the developed taxonomy and quality of suggested definitions, a closed card sort approach to validate the first level of the taxonomy and a tree testing exercise to test the level of agreement among the participants on the choices made in the categorization of a range of concepts. The concepts to be verified with this method were selected among the most ambiguous and controversial ones. Committee 2 was composed by 15 people, which is an agreed optimal number of participants according to literature [51]. Also for cards sorting exercises, 10–15 participants are considered sufficiently representative [52].

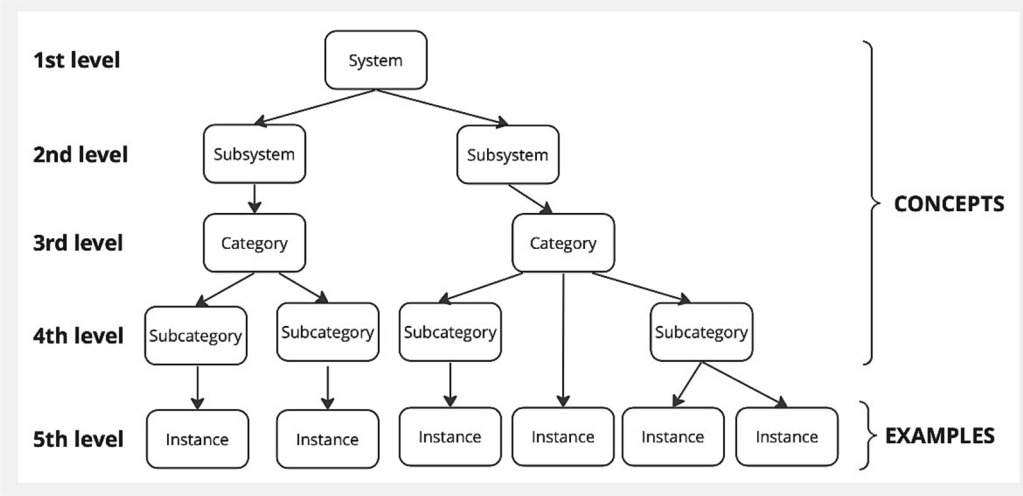

Fig. 2. Schematic Structure of the Taxonomy.

The survey aimed at validating the suggested definitions for every term in the initial proposal. Each term and its definition were presented to the respondents, who were asked to determine whether they agreed with the provided definition or not. In case of disagreement, the respondents were asked to provide their own definition for the given term. After all the terms and definitions were introduced, the respondents were asked about the completeness of the suggested glossary and had a chance to propose additional relevant terms.

Card sorting is a commonly used technique in the process of taxonomy design [53]. It provides the designers with user experience information. Different approaches of card sorting can be used depending on the taxonomy design phase. Open card sort is usually used in the starting phase of taxonomy design. The participants are given a set of terms which they need to classify in groups defined by themselves. This way, we get the categories that the participants see for the given terms. With closed card sort the participants are given the set of terms and predefined categories. This approach is used when at least the draft of the taxonomy is already designed. We can test if the participants put the terms into the expected categories. In our study, we used closed card sort to validate the second level of our taxonomy.

Tree testing is a method to test the whole hierarchical tree of a taxonomy. The participants are provided with the tree structure of the categories (taxonomy) and the instances. Each instance has to be put to the final level of the hierarchy (end nodes of the hierarchy). The analysis of the results gives the insight whether the participants agree on the domain understanding represented in the taxonomy by assigning the foreseen category for the given instances in the designed taxonomy tree.

2.3. Step 3 – Results refinement and representation

Following on from the user trials, the definitions were reviewed to separate out examples and illustrations, and ensure that the definitions were a single phrase that can be directly substituted for the term being defined. Terms and definitions that depended on their position in the hierarchy such as ‘Other laws’ were redefined to make them self-sufficient. This ensures that the definitions are distinct from any observations or examples and helps to eliminate self-referencing and recursion. The results of the refinement were once again discussed by Committee 1.

The end result is a list of agreed concepts that are relevant to the building permitting domain, and their definitions. This list is structured in a hierarchical way, thereby forming a taxonomy. It is then represented using the Simple Knowledge Organization System (SKOS) which is a standard way of representing controlled vocabularies, taxonomies and thesauri [54].

2.4. Step 4 – Final validation within a case study

After final setup of the taxonomy, we assessed the validity and usefulness of our taxonomy in real-world settings, we engaged with an interviewee in a post-analysis review process. The participant of the original interview based on the EUnet4DBP study (see section 1) were interpreted and categorized according to the taxonomy. The participant was asked to evaluate the application of the taxonomy to the transcriptions and was presented with their original interview transcription alongside the annotated version, where taxonomy terms replaced certain words or phrases. He was asked to reflect upon the accuracy and suitability of these substitutions and whether the application of the taxonomy captured the essence of participant’s professional language and thought processes accurately.

This approach added an essential layer of feedback and refinement to our methodology. It provided invaluable insights into the applicability and robustness of the taxonomy from the perspective of those working within the system. This ‘insider’ perspective helped us refine and adapt the taxonomy to better align with the realities of professional practice within the building permit system. The feedback assisted in enhancing the validity and reliability of our research. Any discrepancies, ambiguities, or misunderstandings identified by the interviewees are discussed to refine the taxonomy and its application.

3. Results

The taxonomy was drafted and iteratively improved with the feedbacks and results coming from each methodology step. Such progressive results are presented in the following subsections 3.1.-3.3.

3.1. Initial taxonomy draft

As explained in the methodology section, all the relevant concepts were initially collected and defined by the authors (through workshops and supported by data extracted from BPMN maps, and based on the principles of system theory). The result of this stage is an initial taxonomy, providing both a hierarchical structure for the components of the building permitting system, as well as definitions for each concept.

As a first step, four subsystems were identified to be part of the building permit system: legislative system, organizational system, technological system, and procedural system. Subsystems can be further divided in categories as illustrated in Fig. 3.

The legislative system deals with legal and statutory conditions which include two main categories, namely ‘government level’ and ‘rule and regulation’. Fig. 4

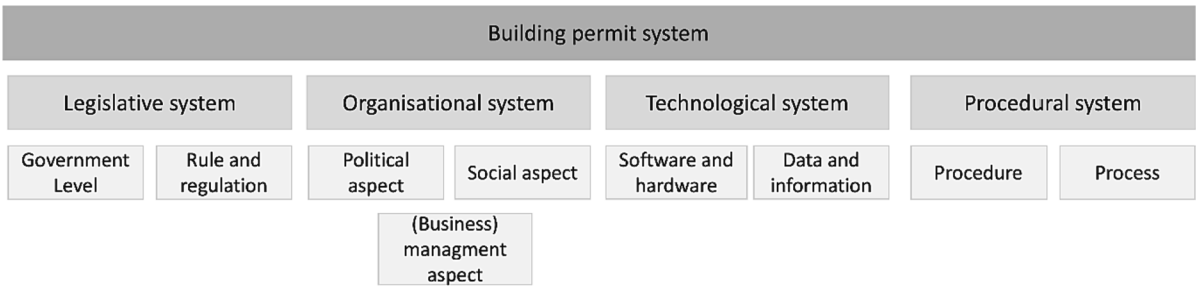

Fig. 3. Overview of the Building Permit System, Subsystems and Categories.

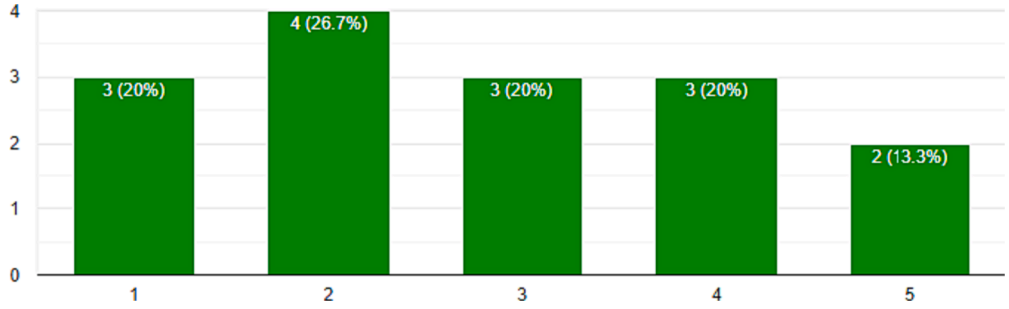

Fig. 4. Familiarity of the Respondents with the Building Permitting System.

The concept'government level' defines on which level certain regulations are applied (e.g., local, regional, federal, national). It defines also the government levels at which the respective laws are defined. In some countries, the building code, for example, contains not only building law-relevant (engineering) content, but also urbanistic content (which would usually be assigned to planning law). The number and diversity of legal texts have a significant impact on digitization because the more legal texts are taken into account, the more difficult and complex it is to convert regulations into machine-verifiable rules. Superordinate laws (e.g., at the national or state level) are often generic, with individual local governments issuing their statutes, which can have both planning and building law content.

The concept'rule and regulation' aims at the classification of laws. Furthermore, specific technical standards on building permitting need to be taken into account like the XBau standard in Germany, which regulates the information exchange between stakeholders in the building permit review [55].

The organizational system considers the aspects involved in the building permit system, which are related more to human behaviour and management systems, as political, business management and social aspects.

For example, the concept'business management aspect' is considered under organizational system. It includes on subordinate level, the internal structures of the individual municipalities and building permit authorities are specified under this aspect. Larger authorities must cope with more staff and a higher volume of applications. Therefore, the authority structure is often divided into smaller departments or divisions. Various concepts can be used as a basis. For example, there may be separate departments for Planning and Building. In this case, the process would be divided into two stages. In addition, specific authorities may oversee particular aspects. For example, 'fire-fighters departments' are often in charge to check the fire safety regulations. In smaller authorities, on the other hand, it may be the case that one person or team is responsible for all aspects of the building permit review as well as other regulatory tasks (e.g., social welfare applications). The'-financial aspect' is one more aspect to be considered.

Another important aspect of the organizational system is the social aspect. This relates to the people who are confronted with the building permit review regularly, that means first of all the employees in the building permit authorities. Depending on the authority, the employees can take on different roles. For example, administrative and technical staff may have different tasks during the building permit review. The roles can also be further divided (planning and building or site inspection). People's perceptions must also be taken into account. This concerns, the level of awareness, acceptance, and working conditions of the public officers. Moreover, an important aspect is related to the knowledge and skills of the people involved in the overall building permit workflow. It determines the level of access to the building permit system at the different levels of digitalization.

The technological system implies all technology to be considered in the context of a building permit. This includes data and information as well as software applications and hardware that can be used as part of the building permit review.

Tool, software and hardware refer to all kinds of software and hardware involved in the permitting system, which are in turn divided into the software involved in the checking of the regulations from BIM and GIS data; and the software composing the platform serving the exchange of data and effective communication between the involved stakeholders throughout the whole process. Since the focus is on digitalization, we decided to use the terms'software' and'hardware' along with'tools', however, possibly manual tools and methods and analogue systems can also be included in this category.

Data and information define the kind of support, specifications and format the data must comply with for successful communication between the involved parts. A digital system implies the use of digital data, in particular, 3D information systems are foreseen, such as BIM and (3D) GIS or 3D city models. Open standards should be used as a reference for data models and formats. The integration of different kinds of data is a further technological challenge to be taken into account as part of the building permit technological system.

In the procedural system, two different categories have to be considered: 'procedure' and 'process'. Procedures are different types of administrative operations. For example, in several countries, small building projects or renovation works only have to go through a simplified building permit procedure. Depending on the procedure, legal regulations are cross-checked on the part of the authority. Certain

procedures are therefore easier to digitize or automate. Another example is the notification to record the use of the building. While in some countries this step only requires a document for archiving, in other countries it is accompanied by a careful inspection of certain stages of the constructed building.

In addition, in the procedural system the concept 'process' is considered. Processes refer to detailed processes of a building permit review by individual authorities. The legal framework usually contains only rough guidelines regarding the individual processes, which is why each authority (also depending on its conditions, such as size, number of employees and number of applications) can interpret ambiguities in the regulations themselves to come to reasonable decisions about building permits. For example, in the context of digitization, processes play an essential role because, on the one hand, they need to be adapted and, on the other hand, they have great potential for a more efficient process and more robust decisions.

3.2. Validation (committee 2)

Validation stage was divided into three parts, one for evaluating how comprehensive the suggested system is, both in terms of completeness and in terms of accuracy of the definitions. The second and third parts aimed at validating the proposed structure. The participants of the validation stage were members of the EUnet4DBP [6], therefore professionals with knowledge and interest in the domain. The participants were presented with a brief overview of the purpose of this work and were asked to answer a survey (part 1) and engage in a cards sort exercise (part 2) as well as a tree testing exercise (part 3). It is important to note that the proposed hierarchy for building permitting and the complete list of concepts that make up the proposed taxonomy were not presented to the participants prior to part 1.

3.2.1. Enhanced consensus on concepts definitions

For part 1, 15 complete responses were collected. As an introductory question, the respondents were asked to rate their familiarity with the building permitting system on a scale of 1–5 (1 being "It is part of my everyday work", and 5 being "Somewhat familiar"). As seen in Fig. 2, majority of respondents are very familiar with the domain. Note that all participants are part of a working group on the subject of permitting, as we can see two of them are less experienced. The vast majority of the participants have 2–5 years of experience in the building permitting domain, most of them in research (10 participants overall). The backgrounds of the participants vary from civil engineering (5 participants), Geo spatial science (3 participants), architecture (3 participants), and the rest in structural engineering, organizational science and operation science. The participants include representatives of different countries, three participants from Spain, two from Portugal, from the UK and from Italy, one participant each from Romania, Belgium, Finland, North Macedonia and the USA.

Based on the responses, out of a total of 51 presented concepts and definitions, 31 % of definitions were accepted and agreed upon by all respondents (100 % agreement). As seen in Fig. 5, 39 % of concepts were agreed upon amongst 93.3 % of respondents. The rest of the concepts received 86.7 % agreement and lower. The lowest agreed upon concept is"rules and regulations", for which only 66.7 % agreed with the provided definition. Note that disagreement can mean either disagreement with the chosen term that describes the concept, or with its definition. The list of concepts classified based on the agreement rate of the participants is provided in Fig. 6. Based on the obtained results, the definitions were re-evaluated and refined. The refinements stage relies on the responses and on the comments provided by the participants. In some cases, the provided comments suggest that only a minor revision is needed, in others we can conclude that the concept itself is not expressing the intended meaning. Therefore, as described in the results section, some of the terms were also rephrased.

3.2.2. Enhanced consensus on the taxonomy structure

The closed card sort exercise (part 2) was completed by 17

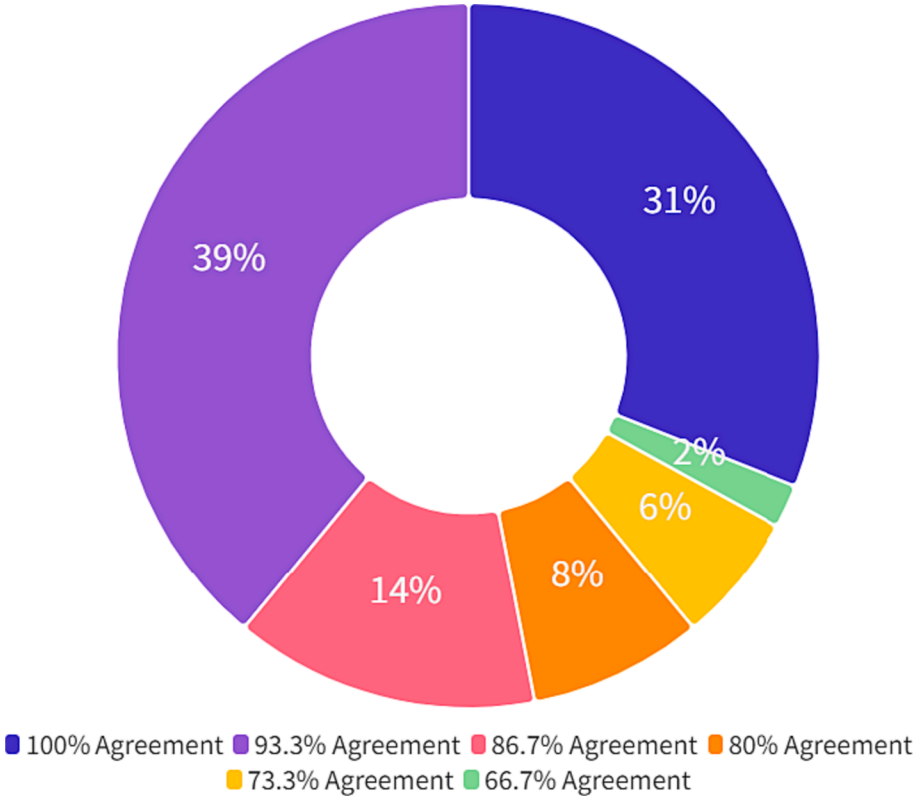

Fig. 5. The percentage of concepts that were agreed upon among the participants of the validation stage (committee 2).

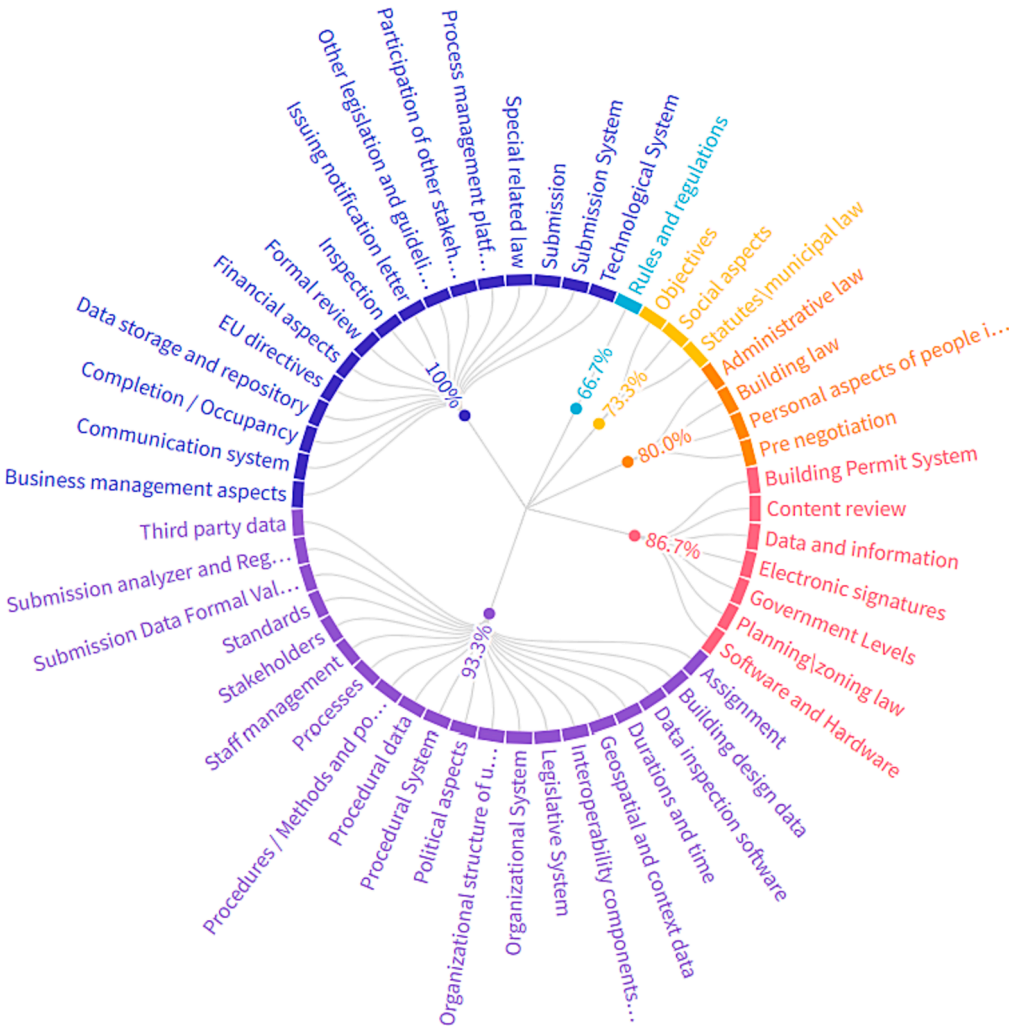

Fig. 6. Classification of the concepts presented in the survey based on the percentage of agreement amongst the participants. This reflects the opinions of the participants on the terms and on the definitions.

participants. According to the study of Lantz [56], the number of participants is sufficient to get valuable results. In addition, the variety of backgrounds, expertise and geographical provenance of participants increases the value of the sample for the test. Three participants declared themselves as experts, nine as competent, four as familiar and one as knowing something about the field of building permitting. The participants come from different countries, three are from Spain, three from Italy, two from Portugal, two from UK, one each from Estonia, Belgium, Romania, North Macedonia, Germany, Turkey and the USA. In the following, the data is given for 16 participants as we are one participant wished to stay completely anonymous. Thirteen of participants have more than 10 years of experience in construction industry, two 5–10 years and one less than 5 years. Thirteen of the participants also have more than 5 years of experience in building permitting and three have between 2 and 5 years of experience. The background of the participants is diverse with five of them having civil engineering background, four geospatial science, three architecture, one mechanical engineering, engineering, operations research and business administration. Their roles vary from researchers (13), public administration (2) and consultant (1). At least seven of the researchers have a dual role and work additionally in the industry as architect (3), engineer (2), software developer (1) or in public administration (1).

The Table 2 summarizes the results of the closed card sort using the popular placement matrix. All but three of the concepts (marked red in the table 2) that were provided to the participants were classified correctly by the majority. The concepts “Participation of other stakeholders”,”Durations and time” and “Procedural data” were not correctly classified by the majority of participants. Although correctly placed by the majority, some terms had lower correctness percentage, with false placements differently distributed. Some of the terms have only one alternative placement, while some have two or even three. This indicates how terms can be related to different systems and underpins the importance and the need for their unambiguous definitions.Table 3.A..

3.2.3. Enhanced consensus on the concepts categories

The tree testing (part 3) results are summarized using a bar diagram (Fig. 7). In total, 16 participants finished the tree testing exercise. All but two participants completed all nine tasks. One participant skipped one task, and the other skipped two tasks. The tree test exercise participants were the same as for card sort exercise with one less participant from Romania, whose expertise is declared as competent.

The exercise took the participants from 3 min to 16 min. However, only two participants took more than 5 min. The overall success percentage for all tasks combined is 52 %. In 85 % of all tasks the participants selected the answer (right or wrong) without backtracking (directness). Dark green shows the percentage of participants that agreed with the assigned category without deviations. Light green shows the percentage of participants that agreed with the assigned category but went also through other branches of the tree. Light red represents the participants that were partly on a consistent path, but finally selected a

Table 2
Popular Placements Matrix of the Closed Card Sort Exercise.

	Legislative system	Organisational system	Technological system	Procedural system
EU directives	100			
Special related laws (e.g., Environmental)	100			
Administrative law	94	6		
Building law	94			6
Other legislation and guidance	94	6		
Planning / Zoning law	94	6		
Statutes / Municipal law	88	12		
Standards	65	18	18	
Staff management		100		
Organisational structure of units (internal and external)	6	88		6
Stakeholders (e.g. applicant, agencies of public interest)		88		12
Personal aspects of stakeholders involved	6	82		12
Objectives	18	71		12
Financial aspects	12	59		29
Participation of other stakeholders		59		41
Interoperability components and solutions			100	
Data inspection software			94	6
Data storage and repository in the different phases of BP and building life		12	88	
Submission analyzer and regulations' checking software			88	12
Geospatial and context data	6		88	6
Building design data			82	18
Electronic signatures			76	24
Submission data formal validators			71	29
Submission system			65	35
Third party data	6	12	59	24
Communication system		18	59	24
Workflow/process management platform		18	53	29
Submission				100
Durations and time		6	6	88
Inspection		6	6	88
Completion / Occupancy	12		6	82
Pre negotiation	6	12		82
Issuing notification letter	6		18	76
Content review	6	12	12	71
Formal review	12		18	71
Assignment		29	6	65
Procedural data			35	65

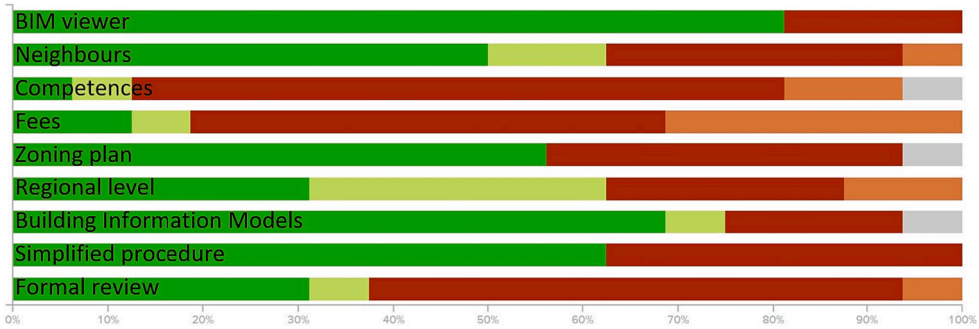

Fig. 7. Bar diagram, representing the results of the tree testing exercise.

different sub-category. The dark red represents the cases of completely different selection of the final category in the taxonomy tree.

The instances 'Competences', and 'Fees' and the concept 'Formal review' have below 50 % correctness. However, the breakdown of the participant's navigation in these cases is different. The majority of the participants see the instance 'Competences' in 'Business management aspects' category for example (Fig. 8).

Fees are a different example, where we do not have a clear majority. This indicates that Fees represents an instance, which the users relate to many categories (Fig. 9).

For Formal review, there is no alternative category which the participants would find more suitable. Still, the dispersion of selected alternative categories is large and contributes to a lower percentage of correct placements (Fig. 10).

The participants did not become familiar with the taxonomy before the tree test exercise. The web interface used for the exercise does not reveal the whole taxonomy to the participants but only the next level in the selected category. This means, that they did not get a broad picture of the taxonomy which explains a relatively large percentage of indirect success. This means, that they did not get a broad picture of the taxonomy which explains a relatively large percentage of indirect success, where the participants find the correct category in the end but first browse also through other categories (light green in Fig. 10).

3.3. Final taxonomy description

To enable easy reuse of the suggested taxonomy and support linkage to external resources, the final results were encoded as a Simple Knowledge Organization System (SKOS) [54], which is recommended by the World Wide Web Consortium (W3C) for representing controlled

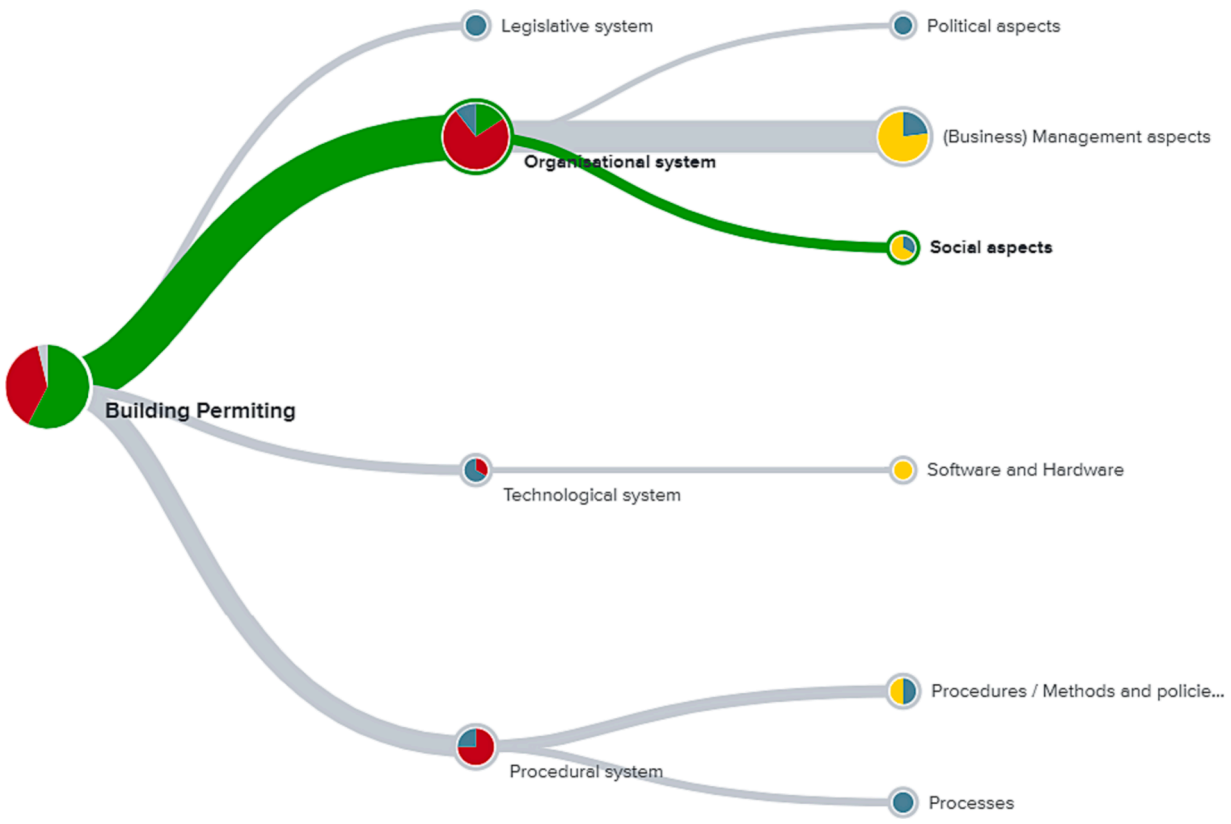

Fig. 8. The Pietree of Decisions for the Term Competences.

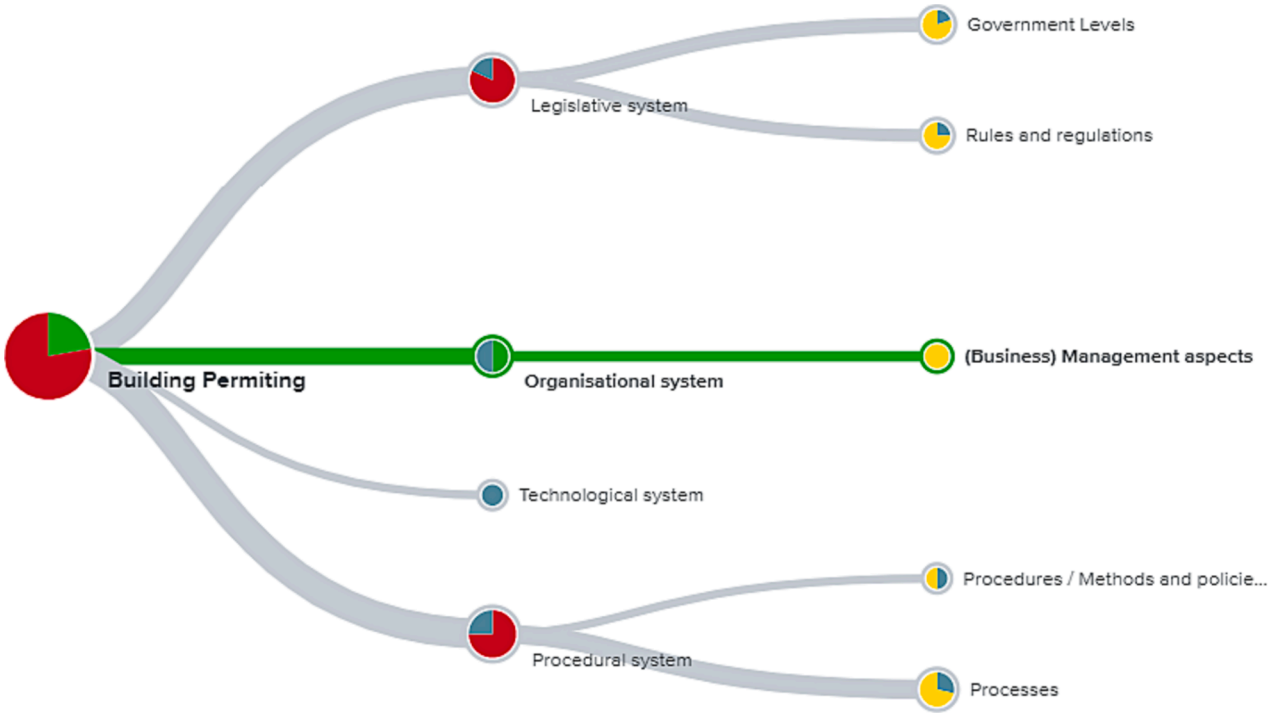

Fig. 9. The Pietree of Decisions for the Term Fees.

vocabularies, taxonomies, thesauri, classifications, and similar systems. SKOS is a standard way to represent knowledge organization systems using the Resource Description Framework (RDF). This allows the developed taxonomies to be distributed and reused.

The main SKOS elements used in the encoding are skos:Concept that represents the main building blocks of the knowledge organization system for building permitting, and the skos:Definition that supply complete and coherent definitions for each of the concepts. The

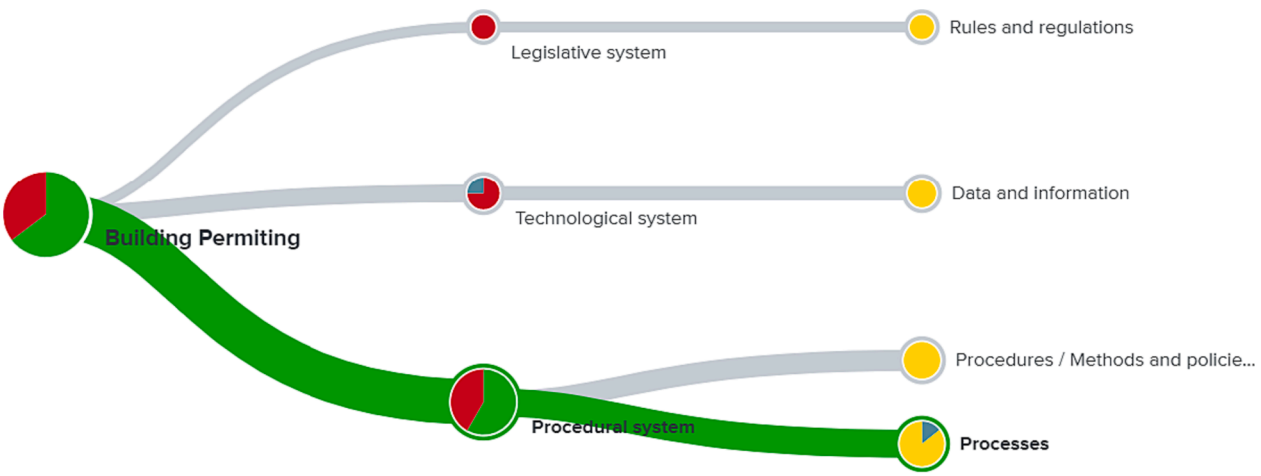

Fig. 10. The Pietree of Decisions for the Term Formal Review.

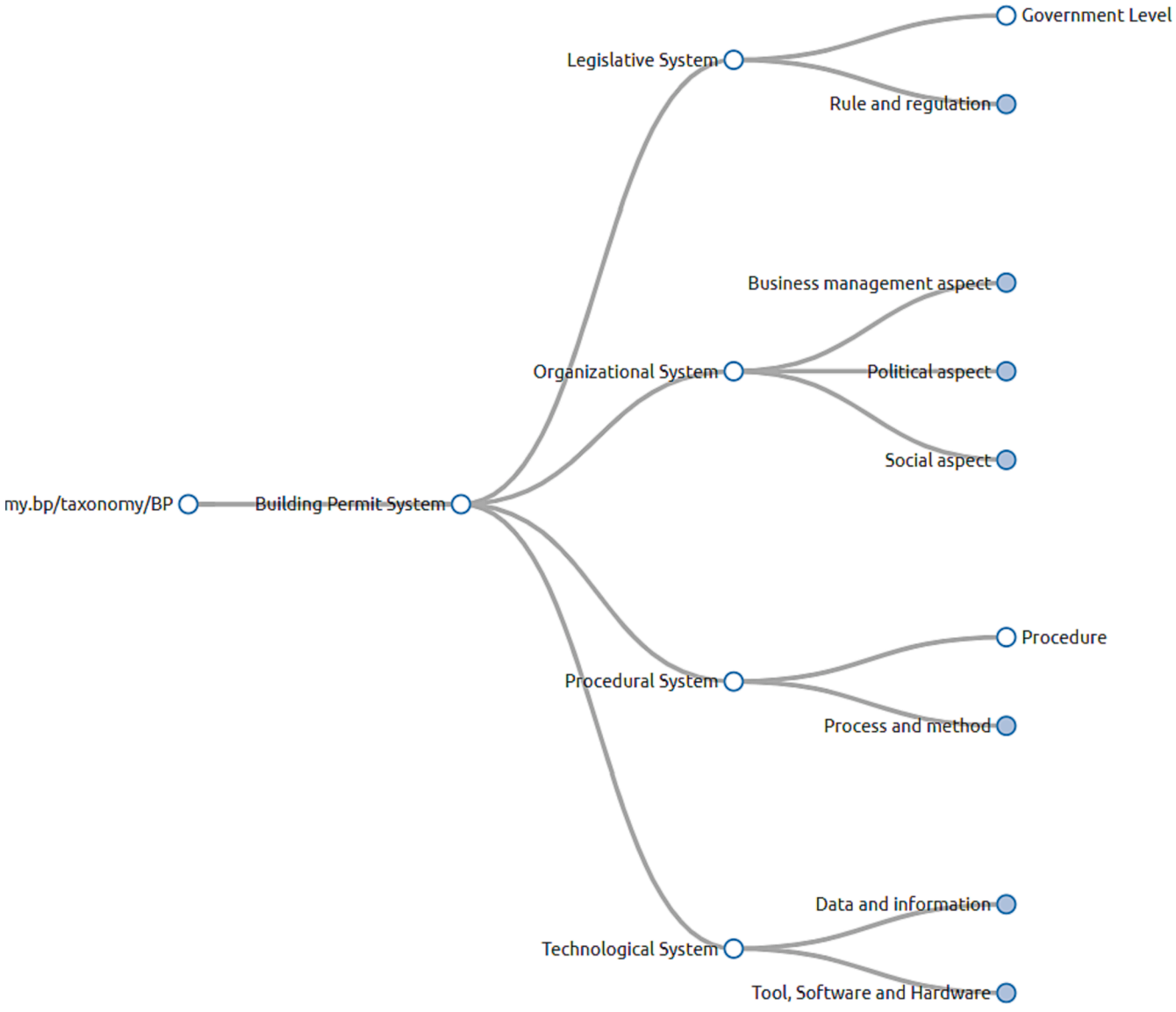

Fig. 11. Overview of the Building Permit System, its Subsystems and the Categories within each Subsystem.

hierarchical structure is expressed through the skos:broader and skos: narrower relationships. SKOS also supports documentation using elements such as change notes, or editorial notes [57].

One of the benefits of using SKOS is that the provided taxonomy can be easily managed, extended and revised. Following the comments of committee 2 participants, we extended the taxonomy to include examples which are represented as skos:example elements. All elements were represented in a structured excel spreadsheet which was then converted to RDF using an excel-to-RDF converter [58].

For the final representation of the taxonomy, the results of all three parts of the validation stage were considered for a final refinement of the concepts, definitions and hierarchy. While some concepts and definitions were mildly changed based on the results of the survey and the cards sort exercises, some were significantly revised in terms of definition or location in the provided hierarchy, and sometimes in both. For example, the concept "Objectives" which was originally an instance under the "Business management aspects" category, was moved to the "Political aspects" category, the concept and its definitions were revised as well. The definition provided in the validation stage was "Objectives of the municipality or the mayor. The philosophy of the city.", based on the comments from participants, the concept was refined to "Strategic objectives", defined as "Overall vision, goals and desired outcomes of the authority.".

We have removed the "Durations and time" from the taxonomy as it is a broad concept, not specific for our target domain. It also confused the participants during the cards sort exercise. The concept of"Participation of stakeholders" was perceived too general (although relevant), therefore it was divided into" Participation of other agencies" and" Participation of the public". Additionally, it was recognized that the term "Formal review" does not express the intended concept and the given definition so it was revised to "Administrative check". An additional concept was added to the taxonomy based on the comments from the participants. The additional concept is 'post- decision' and it is defined as actions and resource taken after a decision, including notifications to mapping and utility authorities or possible appeals and judicial reviews.

In this final stage, revision of concepts that were mostly agreed upon was of minor rewording, unless the comments from the participants suggest a more significant change is needed. The final taxonomy is illustrated in the figures below. Fig. 11 presents the basic structure of the building permitting system, its subsystems and the categories within each subsystem. Detailed views of each of the subsystems, Legislative, Organizational, Procedural and Technological are illustrated in Figs. 12-15. Detailed definition of each of the concepts (in all levels) are provided as supplementary data using the SKOS encoding. The taxonomy is currently hosted in the OGC 'Registry for Accessible Identifiers of Names and Basic Ontologies for the Web' (Rainbow) [59], from which it can be explored and visualized via the following link: https://defs-dev.opengis.net/vocprez-hosted/object?uri=http%3A//data.taxonomy.bp/taxonomy/BP.

4. Use case verification (step 4)

For the practical validation of our taxonomy, we involved two interviewees in a post-analysis review. They were asked to assess the taxonomy's implementation on their transcript, which was presented alongside the version annotated with taxonomy terms. The interviewees were to assess the accuracy, aptitude, and whether the taxonomy

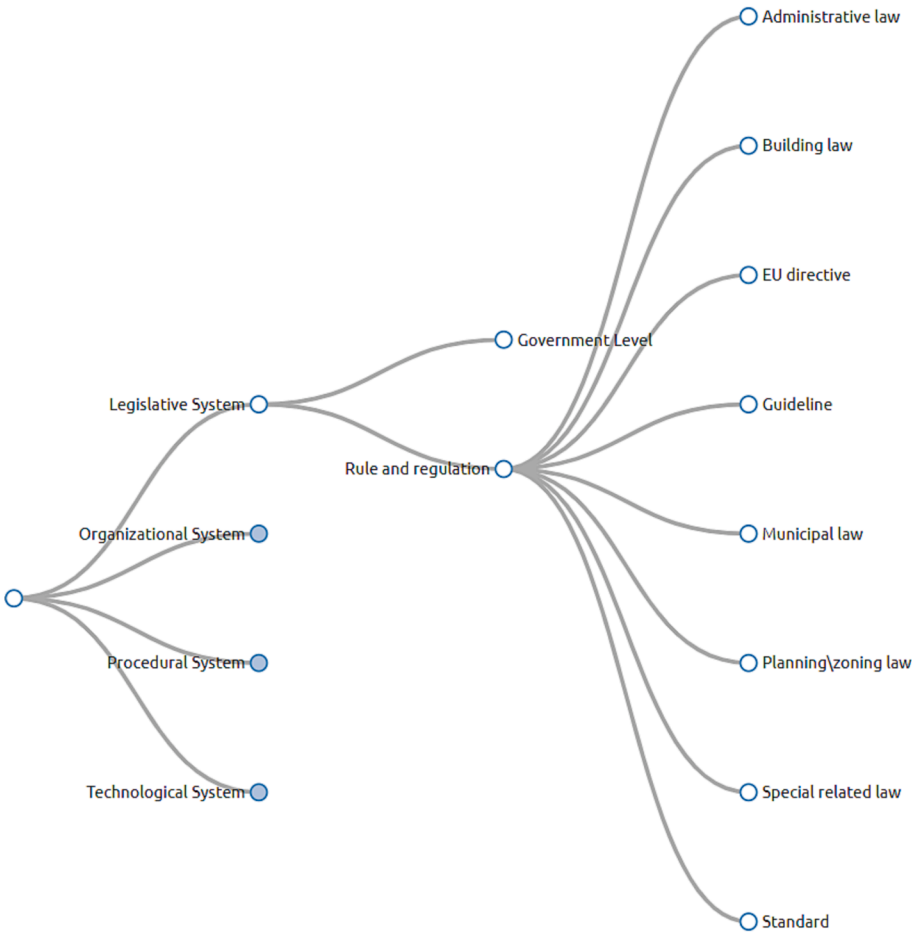

Fig. 12. Legislative System, its Categories and Sub-Categories.

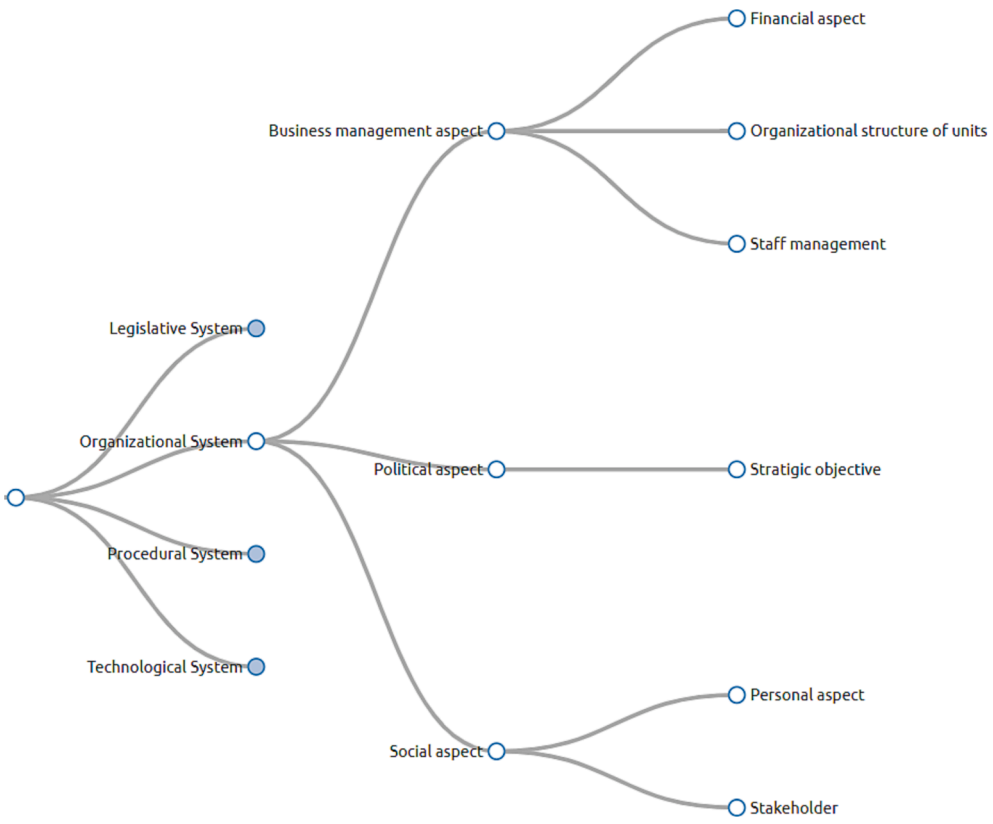

Fig. 13. Organizational System, its Categories and Sub-Categories.

accurately encapsulated their professional language and thoughts. This feedback was helpful in refining our methodology and provided insights into the taxonomy's feasibility and durability from an 'insider' viewpoint, enabling us to adjust it to the realities of professional building permit system practice. The feedback also served as 'member checking' to improve the credibility and consistency of our research. Any identified discrepancies, ambiguities, or misunderstandings were discussed to fine-tune the taxonomy and its usage. The interviewees were two building administration professionals from Denmark and Romania who have worked with building permitting for more than five years (6 and 22 years), and who have 6 and 35 years of experience in the construction industry in general. The interviewees' field of expertise is building engineering and civil engineering. The two interviewees were selected based on regional differences.

4.1. Results of annotated and reviewed transcription snippet

The results of the review of the taxonomy are presented below, where the raw transcription is listed first from the interview. The transcription appears below annotated with bold text highlighting concepts that have been replaced with the taxonomy and colours, green (high accuracy and suitability), yellow (medium accuracy and suitability) and red (low accuracy and suitability). The results from the snippets can be seen in Table 3, Table 4, Table 5 and Table 6. Four snippets were reviewed, and the results are summarized at the end of the section. The first two snippets were taken from the first interview conducted in Denmark, while the last two snippets were collected from the second interview taken in Romania. The interviews were translated from the original languages (Danish and Romanian) into English and then subsequentially reviewed in English.

4.2. Results and discussion of the use case

The application of our taxonomy to the analysis of interview transcripts has shown to contain most of the meaning based on the post-review of the interview with the interviewees as can be seen in Table 7. It has enabled a structured and systematic approach to the analysis of qualitative data, making it possible to identify, classify, and quantify key concepts and themes in a consistent manner. The taxonomy guided an understanding of the building permit system, allowing the recognition and exploration of crucial elements like legislation, procedures, stakeholders, and technological systems. By using this taxonomy, we were able to break down complex narratives into understandable segments, providing us with a comprehensive picture of the building permit system.

The taxonomy's structure, with its four levels of increasing specificity, has proven particularly useful in this regard. It allowed for both high-level overviews and detailed analyses, capturing the complexity and intricacy of the building permit system. Furthermore, it facilitated a consistent, repeatable, and scalable approach to data analysis, which is crucial for longitudinal and comparative studies. Moreover, the review process with the interviewees showed that the taxonomy resonated well with their understandings. Even where discrepancies were identified, these provided valuable opportunities for further refinement of the taxonomy, demonstrating its dynamic and responsive nature.

Ultimately, the successful application of the taxonomy underscores its value as a research tool. It showcases the potential of a well-structured, comprehensive taxonomy in aiding our understanding of complex systems like the building permit system. This suggests that similar approaches may be beneficial in other research contexts and fields, affirming the value and effectiveness of our methodological approach.

One point of significant discussion arose around the application of the concept "Stakeholder" within our taxonomy. The term was annotated examplarily for, "Citizen", "Certified Fire Advisors" and "Certified Statisticians" in the annotation of the interview transcripts. However, during the post-analysis review process, the interviewee expressed concerns about the suitability and accuracy of the term when applied to

Fig. 14. Procedural System, its Categories and Sub-Categories.

the "Certified Fire Advisors". It appears that our initial categorization may not fully capture the nuance of roles within the building permit system. Specifically, the term "Stakeholder" might be too broad or generic to appropriately encompass professional roles like that of a "Fire Safety Advisor". This feedback suggests that professionals may perceive their roles in more specialized terms, reflecting their specific expertise and responsibilities within the system.

Another notable focus of discussion emerged regarding the term "Administrative Law". According to the interviewee, in both cases where the term was annoted e.g. "Organizational Regulations" as well as "Internal Rules of Order and Functioning", it suggested rather the organization and functioning regulation as a specific source of labor law which represents the unilateral internal act of the employer, by which he establishes the organization and functioning of the establishment. However, taking the term "Internal Rules" is more precisely referring to the Organizational System, from business management point of view. This states a point that needs to be considered further in the taxonomy. Consequently, the initial categorization seems to miss capturing the distinction between the terms in the building permit system.

In the process of discussing the term "Geographic Information System", which was annotated as "Geospatial and Context Data", another significant point was raised. During the interview, the interviewee stated that while "Geographic Information System" could refer to data representing the existing context and related information, in the present context it refers to "Tool, Software and Hardware".

Out of ten concepts where this term was annotated, the interviewees found one instance to be only of "medium" accuracy and suitability. In the interviewee's view, this statement contained concepts representing "Procedures" and "Procedural data." This underscores a potential overlap or confusion between these two categories in our taxonomy and could signal a need for further distinction or clarity between these terms. The conflation of these two concepts could result in skewed quantitative results, as some mentions of "Procedures" may be better classified as "Procedural data" and vice versa. This feedback also points to a broader issue concerning the dynamic nature of building permit systems, which often entail a complex interplay between procedural and data elements. Therefore, it suggests that a more nuanced or differentiated approach may be needed in our taxonomy to capture the building permit system's intricacies fully.

The results from the snippets showcased the need to make a qualitative assessment of the usability of the taxonomy. Here we identified potential misunderstandings of our taxonomy which signifies the need to make it even more transparent what is meant with each concept to make sure that we limit misunderstandings as much as possible. Moreover, it would be beneficial in a future study to look into how these misunderstandings are manifested into a broader sense (in e.g., a quantitative study like a survey).

5. Discussion

The main aim of this project is to develop a clear, well defined and concise high-level taxonomy for the domain of building permitting. The

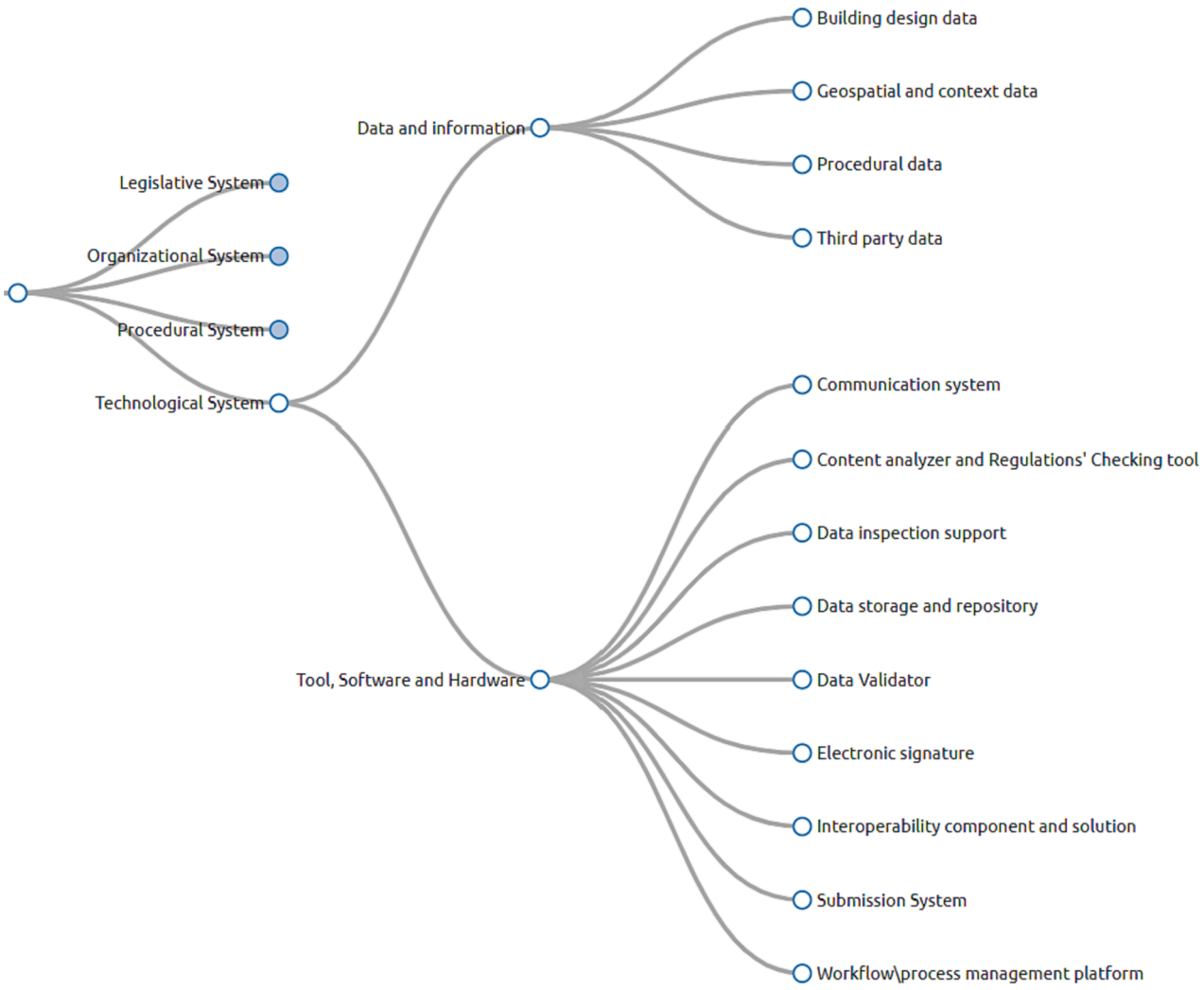

Fig. 15. Technological System, its Categories and Sub-Categories.

Table 3
Annotation using the taxonomy of transcription snippet 1.

Raw transcription snippet 1	Annotated transcription snippet 1
'Yes, the Building Regulations 2018 have certainly contributed to the fact that it has taken longer, also to process cases. I was hired when the Building Regulations 2015 were in force, so I managed to process a little under this building regulations, where it was stated that when we applied for a building permit, if it went through, we had to announce the commencement and then they just had to send in a signed declaration at the end, after which the case was actually finished. Building Regulations 2018 was a bit of an upheaval for citizens, consultants, municipalities and everyone in today's Denmark, where we had to familiarize ourselves with the importance of suddenly choosing fire class and construction class, technical conditions they had to choose. There were many citizens who used to have to look for a small outbuilding, where it was suddenly technically difficult to have to search for it out here.'	'Yes, the **Building Law** 2018 has certainly contributed to the fact that it has taken longer, also to **Procedures**. I was hired when the **Building Law** 2015 were in force, so I managed to process a little under this **Building Law**, where it was stated that when we **Procedures**, if it went through, we had to **Procedures** and then they just had to send in a **Procedural data** at the end, after which the case was actually finished. **Building Law** 2018 was a bit of an upheaval for **Stakeholders** in today's Denmark, where we had to familiarize ourselves with the importance of suddenly choosing **Procedures** they had to choose. There were many **Stakeholders** who used to have to look for a **Procedures**, where it was suddenly technically difficult to have to search for it out here.'

Table 4
Annotation using the taxonomy of transcription snippet 2.

Raw transcription snippet 2	Annotated transcription snippet 2
'Yes, there has also been something about certified fire advisors and certified statisticians who have created a funnel, although not so much in our cases. But yes, it was a big change when the building regulations 2018 came, we actually also held some information meetings from advisors where I also participated to explain what the process is, what should you relate to, what should you put in. First, we had to look at what documentation they had submitted regarding statics, for example, and take an assessment of the documentation, the agency then changed the regulations in relation to this with final notification on 1/1-2022, where they jumped back to the declaration that was in the Building Regulations 2015, so now we just had to sign a declaration that the necessary documentation had been sent. Actually, the same as in BR15, on the grounds that it should ease the workload on the part of the case workers. As I am informed of why they chose to change the building regulations, it has been to raise the quality of the building that is being built, because there has been a tendency in BR15 that it was just the declaration you received and not a damn documentation, where you then in principle scrap all that or some of that thinking by reintroducing this declaration. Then it is the citizen's responsibility now, whereas in the past it was a shared responsibility, because we had to go in and look at it.'	'Yes, there has also been something about **Stakeholders** and **Stakeholders** who have created a funnel, although not so much in **Procedural System**. But yes, it was a big change when the **Building Law** 2018 came, we actually also held some **Procedures** from advisors where I also participated to explain what the **Procedures** is, what should you relate to, what should you put in. First, we had to look at what **Procedural data** they had submitted regarding statics, for example, and take an assessment of the **Procedural data**, the **Stakeholders** then changed the **Building Law** in relation to this with **Procedural data** on 1/1-2022, where they jumped back to the **Procedural data** that was in the **Building Law** 2015, so now we just had to sign a **Procedural data** that the necessary **Procedural data** had been sent. Actually, the same as in **Building Law**, on the grounds that it should ease the **Staff management** on the part of the **Stakeholders**. As I am informed of why they chose to change the **Building Law**, it has been to raise the quality of the building that is being built, because there has been a tendency in **Building Law** that it was just the **Procedural data** you received and not a damn **Procedural data**, where you then in principle scrap all that or some of that thinking by reintroducing this **Procedural data**. Then it is the **Stakeholders** responsibility now, whereas in the past it was a shared responsibility, because we had to go in and look at it.'

Table 5
Annotation using the taxonomy of transcription snippet 3.

Raw transcription snippet 3	Annotated transcription snippet 3
'Yes, electronic data is transferred, for example when we do the function check in that area. We have GIS geographic information system partially implemented, and there we have information about the function, all the Zonal Urban Planning are included which are the provisions of the Zonal Urban Planning, so digital databases are also used in the documentation verification procedure, but otherwise for the permit documentation, most of the documents are physical and not digital. So the digital part is the verification of the general urban plan, the zoning plan and the drafting of the document in digital format. That's about it.'	'Yes, **Data and Information** is transferred, for example when we do the **Content Check** in that area. We have **Geospatial and Context Data** partially implemented, and there we have **Data and information** about the function, all the **Planning/zoning law** are included which are the provisions of the **Planning/zoning law**, so **Tool, Software and Hardware** are also used in the **Procedures**, but otherwise for the permit **Procedures**, most of the **Data and Information** are physical and not digital. So the digital part is the **Content Check** of the general urban plan, the zoning plan and the drafting of the document in digital format. That's about it.'

purpose is to support consistent interpretation of the current status of building permit systems and comprehensive planning of its digitalization. To achieve that goal, and to enable an efficient implementation of the provided taxonomy, we bring together the terms and definitions that were collected across information sources (BPMN maps, expert knowledge, focus groups) into a structured, controlled categorization.

As a first stage, term collection, definition and structuring were performed by extracting knowledge from literature and BPMN maps which describe permitting processes in different countries. In the validation stage, we aim to establish the basic professional terminology in the building permitting domain through a survey. The participants of the survey were first presented with terms and definitions, in an unstructured way, regardless of the proposed hierarchy of building permitting system. It is important to develop the components and their definitions, independently of the proposed structure to ensure that the meaning of each concept is concise and accurate. Although most of the concepts and

Table 6
Annotation using the taxonomy of transcription snippet 4.

Raw transcription snippet 4	Annotated transcription snippet 4
'There are also organizational regulations, which are established by the job descriptions, by the internal rules of order, by the ROF: internal rules of order and functioning, but of course the verification of the document is done based on the legal provisions which tell us directly what is the legal content of the documentation in order is to issue the authorization document.'	'There are also **Administrative Law,** which are established by the job descriptions, by **the Administrative Law,** but of course the **Content Check** is done based on **the Rule and Regulation** which tell us directly what the Building Law (Building Code) of the Procedure in order is to issue the authorization document.'

Table 7
An overview of the results of annotated and reviewed transcription snippets.

Term	Total Count	Concepts from Snippet 1	Concepts from Snippet 2	Concepts from Snippet 3	Concepts from Snippet 4	Red	Yellow	Green	Accurracy and suitability in percentage
Stakeholders	7	2	5			4		3	43 %
Procedural System	1	0	1					1	100 %
Procedures	10	5	2	2	1		1	9	90 %
Procedural data	8	1	7					8	100 %
Staff management	1	0	1					1	100 %
Building Law	9	4	4		1			9	100 %
Data and Information	3			3				3	100 %
Content Check	3			2	1			3	100 %
Geospatial and Context Data	2			1		1			0 %
Planning/ zoning law	2			2				2	100 %
Tool, Software and Hardware	1			1				1	100 %
Administrative Law	2				2	2			0 %
Rule and Regulation	1				1			1	100 %
Mean value									**79 %**

definitions were agreed upon (31 % of concepts agreed by 100 % participants and 39 % of concepts agreed upon by 93.3 % of participants), the comments often provided much more significant insight. Often, despite high disagreement rates, we learned from the comments that only very mild rephrasing is needed for a comprehensive and clear definition.

As explained in the methodology section, part of the validation stage was also revisiting the proposed hierarchy. Although the card sort exercise results can be characterized as very good, we must emphasize that the card sort exercise tested just the placement of the lower-level concepts (3rd and 4th) into the 2nd level concepts. We can relate these results to the first click analysis of the tree testing exercise, where we analyze the first selection of 2nd level concept, where we also see a high success rate (Fig. 16) for all but one instance (Fees), which was selected for the test due to its ambiguity and broad scope. We can reasonably assume that the general top-level taxonomy is sufficiently unambiguous.

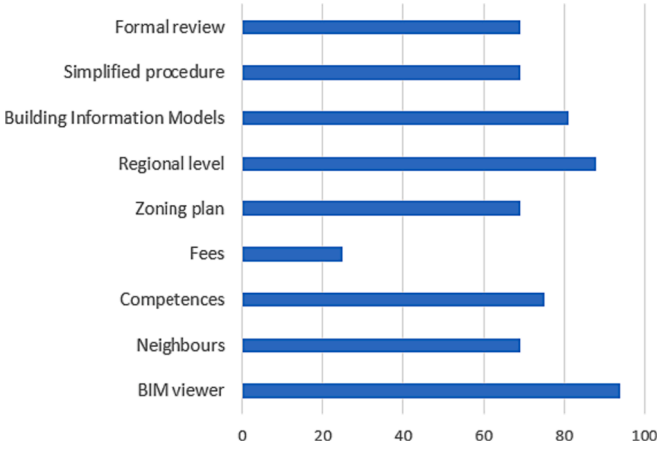

Fig. 16. The Success Rate of the First Click in Tree Test Exercise.

The tree test exercise results however do not show so high success rates, which can at least partly be attributed to the following factors:

(a) The web interface that was used for tree testing did not show the whole taxonomy structure to the participants as the aim is to test if the participant can correctly navigate the tree towards the final concept. We can assume the participants were trying to discover other related concepts to get a broader picture of the taxonomy during the exercise before finally deciding for the most suitable one. We can therefore assume the results would be better if the whole taxonomy structure would be provided to the participants throughout the exercise.

(b) The participants were first asked to complete the survey containing the definitions, but these definitions, were not available to them later during the tree test exercise, when they could be beneficial to aid the selection of appropriate concepts.

(c) As shown in the results section, technical and legal instances were better classified by the participants than organizational ones, which can be attributed especially to the professional background of the participants (mostly technical or legal background).

The developed validation and testing (Step 2 and 4 of the methodology) allowed to obtain a taxonomy respecting the quality criteria listed by Juliadotter [18] (Section 2.1). We focused on the following: comprehensiveness, completeness, mutual exclusivity, unambiguity, and usefulness.

Comprehensiveness and completeness were achieved mainly using the questionnaire, as the participants were asked to provide feedback for

each concept and its definition. In addition, the participants were asked for possible missing terms, to ensure the comprehensiveness of the taxonomy further. All the feedbacks were considered in the following revision of the taxonomy. Card sort and tree testing exercises supported the validation of mutual exclusivity and unambiguity. The users were also asked to insert a comment if they found any issue with the concepts. The results of the exercises enabled us to revise the structure and the categories, especially to reduce the ambiguity and improve determinism.

Usefulness of the taxonomy has finally been proven by the case study, where the proposed taxonomy was used to classify the terms in a snippet from the interview for a post-analysis with one of the officials in the building permitting authority.

A unique challenge in our study was the need to reconcile linguistic differences. The challenge clearly emerged, first, in the step 2 of the methodology, during the checking of definitions with the committee 2. In this case, we could see that some of the most controversial terms and definitions could be identified in words which could have alternative meanings or false friends or small discrepant meaning nuances in other languages (e.g., the term 'competence'). In addition, linguistic differences were noted between the original interview content and the taxonomy, both when considering the BPMN maps (step 1.2) and during the test within the case study (step 4). For example, in the case study test (step 4), the interview was conducted in Danish and were subsequently translated into English to align with our English taxonomy. This translation process presented both linguistic and conceptual challenges.

Language is not merely a tool for communication; it also carries cultural and contextual nuances that may be lost or distorted during translation. Similarly, technical and professional terminology may not translate directly from one language to another. This could lead to misinterpretations or oversights in applying our taxonomy to the interview data. Moreover, given that the taxonomy was developed in English, it inherently carries assumptions and cultural influences from its language of origin.

Hence, our interviewees' feedback was crucial in identifying any discrepancies or misunderstandings that may have arisen due to translation. It helped improving objectivity and clarity of the taxonomy and its components (terms, definitions, structure) in order to suitably support the initial goal.

As the interest in building permitting grows, the defined taxonomy can serve as a knowledge base for further research and developments in the domain. It is useful for "levelling the playground" for researchers from different parts of the world to allow easy and meaningful collaboration on the subject. On the practical side, a taxonomy for building permitting can serve as a unified language across countries, organizations and stakeholders.

5.1. Links to external categorisations

As mentioned in Section 1.3 (Table 1), several thesauri, taxonomies, vocabularies and glossaries exist, which could be related to the different parts of the building permit system. However, a higher-level layer linking them to each other within the context of building permits systems was necessary to obtain a comprehensive description. Notwithstanding this, it is important to reuse the structures which are already provided for the finer granularity descriptions, to avoid redundancies, as well as to link to relevant information stored according to other structures. Fig. 17 represents the possible connections with the existing classification artifacts, which should be considered in more detail to improve and extend this work in the future.

6. Limitations

It is of high importance to base the taxonomy on a comprehensive and agreed upon list of relevant terms. Hence, the stage of collecting the terms relied on various sources (e.g., BPMN maps, literature, expert group workshops). One of the limitations of the implemented methodology is that number of collected responses in the validation stage is relatively small. However, the reached agreement amongst two groups of experts in the field (committee 1 and committee 2) provides a sufficiently firm base for establishing the content covered in the developed taxonomy.

Another limitation is that even with an interdisciplinary committee for the development of taxonomy and several validation approaches, the perspectives considered are limited. For example, most of the participants are architects and engineers, with not much background on organizational aspects. This was reflected during the card sort exercises. In addition, we could not cover an entire global perspective even though the committees include representatives from multiple countries, they were mostly Europe-based. The taxonomy does not include multilingual aspects or synonyms either, which both would be seen as helpful for a common understanding. This remains a future challenge for further research.

The taxonomy can therefore continue to be tested and reviewed and as necessary updated and improved. This includes a constant assurance that the content is up to date, that updates are appropriately revised and validated, and, in the best case, that the taxonomy is made available without restriction on an open accessible repository. However, the higher-level subsystems and categories mostly met consensus by all the committees' participants and can be considered, for the moment, as an agreed structure.

6.1. Directions for future research

As the proposed taxonomy covers a high-level categorization, it became clear during the development that further on a more detailed level for each subsystem has great potential. For example, for the procedural subsystem, detailed BPMN maps could play a role for investigations. BPMN offers a set of diagramming conventions which highlight the actors involved, their processes and decision making and the information transfers between the processes. IDEF0 [60] can complement BPMN by emphasizing, not only the inputs and outputs, but also the constraints and resources required for a process. The organizational system is also a good example of needed further research as it requires a more thorough investigation and integration of additional expert knowledge which was limited in this research.

An obvious enhancement of the provided taxonomy is in the multilingual aspect, on the level of each individual concept. Now that the content is defined (on the high level), each of the concepts can be further investigated to establish preferred labels, alternative labels (synonyms) and translations to multiple other languages.

Further advancement would be an ontology based on the proposed concepts enlarged with relationships. For example, processes are linked by sequencing relationships, resources and constraints have relationships to their processes and actors and organizational units may be arranged hierarchically.

7. Conclusions

Often people approach the task of digitalization, in any domain, from the perspective of technological development and capabilities. Unfortunately, this means that aspects other than the technological aspect are simply overlooked. Moving towards digitalization, in any domain (including permitting), requires a deep understanding of all aspects involved, the whole picture. Namely, any advances in the domain of building permitting require a deep understanding of the system and its components. Currently, research focusing on building permitting is fragmented, focusing on either very specific components or staying on a local level. So far, researchers relied mostly on what they know from their home countries, both in terms of the components for a building permitting system, and in meaning and context. Collaboration on an international scale is extremely difficult as direct translation of the

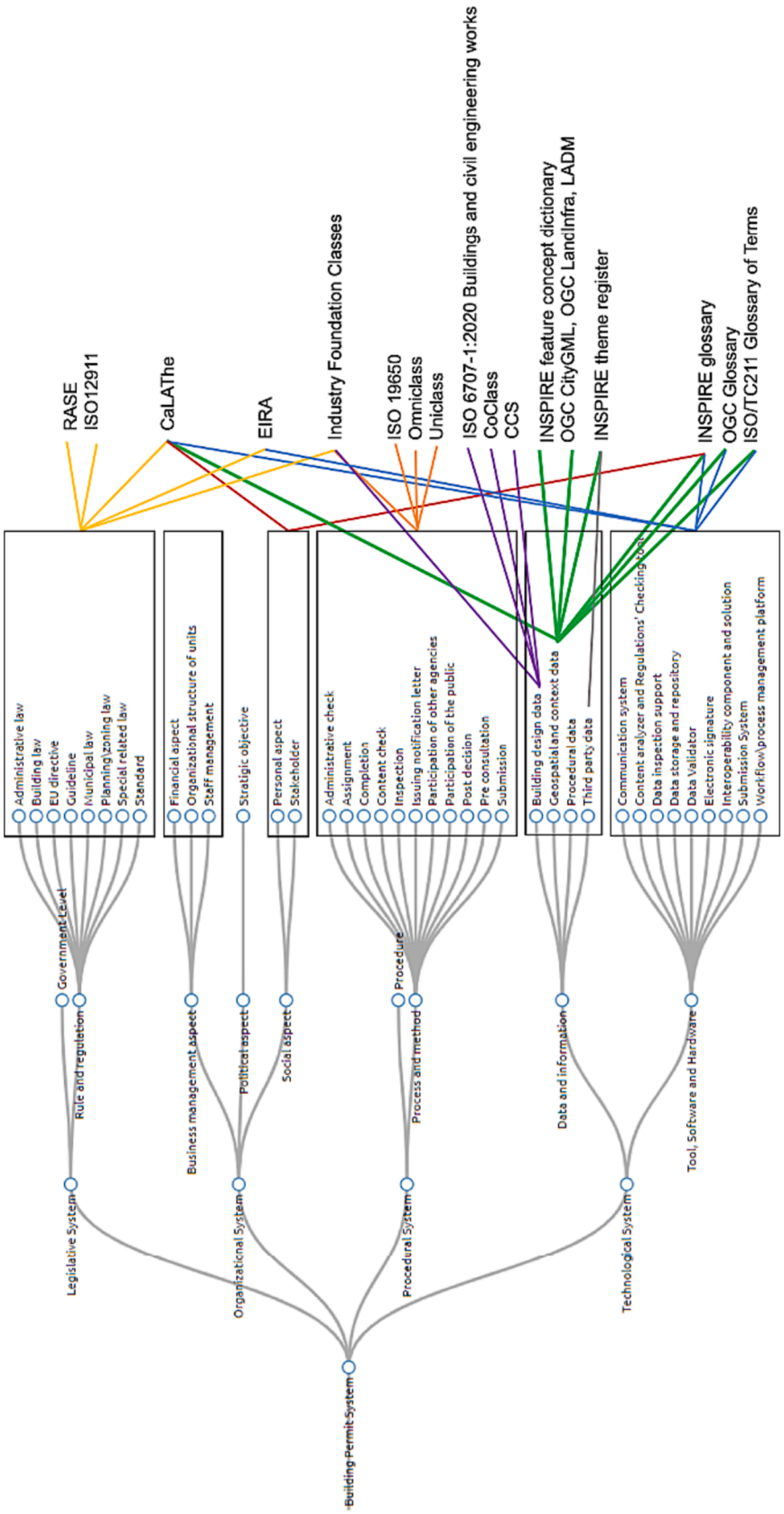

Fig. 17. Potential links of the existing thesauri, taxonomies, vocabularies, and glossaries to the building permit taxonomy categories.

involved professional terms is usually implemented, causing misunderstandings and miscommunication.

This study aims to establish a precise and succinct categorization of components of the building permit system. This classification can be utilized to enhance future advancements in the domain and serve as a foundation for an ontology that organizes the representation and sharing of information related to building permitting. This work employs a methodology that combines literature, interview data sources, interviews, survey, card sorting and tree testing methods. The participants of the various stages of the research are representatives of multiple countries and multiple areas of expertise (engineers, architects, researchers, practitioners). The main goals of establishing the taxonomy are in ensuring its comprehensiveness, completeness and usefulness. At this stage, this was achieved on the high level of subsystems, categories and subcategories.

The result is a taxonomy for building permit system, to serve as a reference to guide and evaluate relevant advancements while providing an overarching framework for their interpretation. This taxonomy offers a valuable asset for researchers, professionals, and policymakers in the construction sector, enabling them to gain a deeper understanding of the building permit system and its forthcoming digital transformation. The taxonomy can support future studies on building permitting by providing a basis for common understanding (unified language) for the scientific community.

For further developments, several potential studies seem auspicious. These include further testing and re-use, the development of an ontology, the enlargement towards the specification of the subsystems, further lingual enhancements, and a more intense study for the alignment with existing and future taxonomies, standards, and glossaries. For future work, it would be interesting to identify other opinions (certain concepts that may not be as common, outliers, etc.), which would require a quantitative research approach based on statistical analysis of a large number of responses. With this study, we have identified important characteristics that will allow us to develop a survey in the future, for example, to better inform the generalizability of our results.

CRediT authorship contribution statement

Judith Fauth: Conceptualization, Data curation, Investigation, Methodology, Project administration, Visualization, Writing – original draft, Supervision. **Tanya Bloch:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft. **Francesca Noardo:** Conceptualization, Formal analysis, Methodology, Visualization, Writing – original draft. **Nicholas Nisbet:** Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Stefanie-Brigitte Kaiser:** Data curation, Investigation, Validation, Visualization, Writing – original draft. **Peter Nørkjær Gade:** Data curation, Methodology, Validation, Visualization, Writing – original draft. **Jernej Tekavec:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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