www.itcon.org - Journal of Information Technology in Construction - ISSN 1874-4753

BIM-BASED DESIGN DECISIONS DOCUMENTATION USING DESIGN EPISODES, EXPLANATION TAGS, AND CONSTRAINTS

SUBMITTED: March 2022
REVISED: June 2022
PUBLISHED: July 2022
EDITOR: Robert Amor
DOI: 10.36680/j.itcon.2022.037

Ata Zahedi, M.Sc.,
Chair of Architectural Informatics, Technical University of Munich, Germany;
ata.zahedi@tum.de (ORCID: 0000-0003-0296-9205)

Jimmy Abualdenien, M.Sc.,
Chair of Computational Modeling and Simulation, Technical University of Munich, Germany;
jimmy.abualdenien@tum.de (ORCID: 0000-0002-8100-9861)

Frank Petzold, Prof. Dr.-Ing.,
Chair of Architectural Informatics, Technical University of Munich, Germany;
petzold@tum.de (ORCID: 0000-0001-8974-0926)

André Borrmann, Prof. Dr.-Ing.,
Chair of Computational Modeling and Simulation, Technical University of Munich, Germany;
andre.borrmann@tum.de (ORCID : 0000-0003-2088-7254)

SUMMARY: *The process of designing a building involves producing design concepts while fulfilling various requirements and regulations. Furthermore, during the project's life-cycle, multiple experts from multiple domains collaborate in developing the different partial models, including architectural, structural, and HVAC among others. Accordingly, clearly communicating the rationale behind design decisions is crucial for developing regulatory compliant designs that also fit the owner's needs. The developed designs are the main deliverables exchanged and handed over. However, these deliverables do not include any explanation of design intentions or documentation of design decisions. Communication among parties and reuse of knowledge are hindered by the absent explanation of existing design. To overcome this deficiency, this paper proposes a methodology for digitally documenting design decisions, incorporating their intention and rationale. Architectural concepts and evaluation criteria are represented in the form of explanation tags as well as spatial and semantic constraints, which are assigned to the individual model elements and properties. Additionally, to document how design decisions fulfill owner requirements and regulatory documents, natural language processing (NLP) is employed to facilitate querying those documents and then the individual requirements are linked to specific elements, properties, and constraints. To evaluate the proposed methodology, a prototype was implemented as a plugin inside a BIM-Authoring tool and multiple real-world use cases are discussed.*

KEYWORDS: *Design Documentation, Design Constraints, Explanation Tags, Design Episodes, Request for Proposal, BIM, Early Design Stages*

REFERENCE: *Ata Zahedi, Jimmy Abualdenien, Frank Petzold, André Borrmann (2022). BIM-based design decisions documentation using design episodes, explanation tags, and constraints. Journal of Information Technology in Construction (ITcon), Vol. 27, pg. 756-780, DOI: 10.36680/j.itcon.2022.037*

1. INTRODUCTION

Construction companies are frequently challenged to innovate and develop customized solutions in order to solve project-specific obstacles. This results in the creation of new knowledge, which should be adequately recorded and maintained (Joe *et al.*, 2013). Designing a building is an iterative task that gradually progresses through multiple phases. Throughout the design process, the design task and its solutions co-evolve (Zeiler *et al.*, 2007). Starting from the early design phases, the maturity of the design increases in the form of more precise and detailed information. Typically, for every project, designers are confronted with a set of requirements and boundary conditions that need to be fulfilled and accounted for. However, throughout the design process, far more knowledge about the client's requirements is gathered compared to the beginning. Furthermore, construction projects are multidisciplinary, involving diverse domain experts, where each has their own perspective and interest (Abualdenien *et al.*, 2020). In many cases, the interests of these experts contradict each other. For example, a structural designer might focus on massive construction due to a high load-bearing capacity. The architect, however, might prefer structures that appear lighter and more slender, whereas the energy consultant recommends using renewable construction materials.

Each building ought to fulfill a combination of requirements and goals that do not necessarily share the same nature. Some of these requirements and conditions are based on objective criteria that could be measured and compared rather quantitatively. Others are based on subjective criteria that could not be easily measured and compared due to their qualitative nature and description. The most essential kinds of requirements that must be fulfilled during the design process are request for proposal (RFP) and building codes. An RFP describes the owner's requirements, including the main form, building use, as well as privacy and sustainability standards. During the design phases, designers use RFP documents as the guideline for fulfilling the owner's requirements and needs (Eastman *et al.*, 2009). However, when looking at real building briefs, one sees that they're often incomplete documents created without a thorough understanding of the design process and technological knowledge and that they require extensive interpretation and addition. Interpreting a project's RFP is typically based on the designers' knowledge and experience (Odusami, 2002). Furthermore, the content of RFPs depends on multiple aspects, such as culture, building usage, and even year of construction (Uhm *et al.*, 2015). For example, a residential house has a much simpler RFP than a residential building or a hospital. Additionally, privacy and sustainability requirements may differ if we compare Middle Eastern countries to the US or today's buildings to those of 50 years ago. In the same context, before permitting building designs to be constructed, they must first fulfill numerous building codes and regulations. Building codes provide prescriptive- and performance-based requirements for different building types, including shopping centers, offices, and educational facilities (Ching and Winkel, 2018). Connecting these RFP documents to building codes via Natural Language Processing (NLP) techniques to further help the architects in this matter is part of this paper's focus.

In everyday practice, it is not mandatory to document the intermediary architectural design choices and variants. Thus, design variants are hardly ever documented as an intermediate step, but mostly only the final result is recorded, e.g. graphically through drawings and views, as well as in the text, or sometimes in digital models (Wiesbaden, 2013). This can lead to reinventing the wheel or making the same mistakes over and over again. We believe that management of design Knowledge is becoming in some senses the core intangible asset of architectural firms competing in the global information-intensive construction industry with ever more complex technologies and demanding clients. The authors argue that comprehensive documentation of design knowledge, sharing it with various stakeholders and decision-makers, and reusing it for future design projects is lacking currently in the majority of the construction industry. However, it is becoming increasingly beneficial and important in the construction industry to manage, share and reuse the design knowledge to improve efficiency and productivity in an industry which is known for its lack of advancement compared to other modern industries (Tang *et al.*, 2006). The value of capturing and documenting design knowledge for architectural firms can be discussed on different levels (Heylighen *et al.*, 2007a; Bracewell *et al.*, 2009):

- first and foremost, to preserve the company's intellectual property and shared knowledge and make it available for reuse in other projects, which in turn leads to fewer redundancies of work and more effective teamwork and greater client satisfaction, and less reliance on the experience and knowledge of key individuals;

- to enable systematic self-criticism and self-improvement inside the firm by learning from mistakes and successes in other projects, resulting in fewer mistakes, fewer resources wasted and more effective decision making and innovative thinking;
- while considering the associated copyright issues, creating the opportunity to share and learn from each other in a profession known to be highly secretive and over-protective of their designs.

This paper addresses the problem of systematically capturing the tacit design knowledge through documenting and explaining the design decisions. Therefore, a novel approach is introduced based on BIM (Building Information Modeling) methodology and Natural Language Processing (NLP) techniques to link client requirements and building codes to design concepts and to record and document design decisions and their explanation in a transparent manner for all stakeholders. Recording and exchanging explanations about the decisions made during the design process will improve mutual understanding and collaboration among all designer parties and domain experts throughout the design process and will enhance the inter-organizational exchange and reuse of the shared knowledge and designs for other future projects and design problems.

The contributions of this paper are threefold: first, the development of multiple concepts and approaches for expressing and documenting design decisions, i.e. *Explanation Tag (ET)* and *Design Episode (DE)* and *Constraints*; second, introducing a framework for parsing, querying, and linking natural text to BIM models: third, the proposed approaches are formally represented using the multi-LOD meta-model and evaluated for practical use through multiple use cases including two real-world building projects. Through the utilization of explanation tags and constraints, various documented design episodes can be created and stored, and later accessed and retrieved using case-based reasoning as well as NLP techniques.

This paper is organized as follows: after the introduction, in section 2, we review the background and related work, followed by section 3 in which we explain the applied methodology and introduced concepts in this paper. Subsequently, at the end of section 3, we discuss the implementation part as proof of concept, and then in section 4, three demonstrative use cases, including two real-world building projects, are discussed to illustrate our novel approach through various design examples. Finally, section 5 summarizes our progress and presents an outlook for future research.

2. BACKGROUND AND RELATED WORK

This section starts by addressing the challenges involved in recording the architectural building design process due to its unique nature with special regard to the importance of early stages of design and then follows with reviewing related literature addressing this problem. During which, BIM and its benefits, as well as its shortcomings, together with the related literature regarding proposed solutions and enhancements for it, are discussed. The use of references in architecture and suggested solutions for knowledge extraction from semantic models will be discussed next. We will also review and discuss similar work in the field of case-based reasoning and design since the proposed concepts of explanation tags and design episodes (among the contributions of this paper) provide opportunities for using case-based reasoning techniques for future retrieval and reuse of design knowledge. Finally, related research in the field of Natural Language Processing (NLP) and design constraints will be covered.

2.1. Architectural Knowledge

Ackoff (Ackoff, 1989) in his data–information–knowledge–wisdom hierarchy (DIKW) described *data* as symbols that denote the attributes of objects and events, whereas *information* is data that has been processed to improve its usefulness. Data and information differ in terms of function rather than structure. Moving up in the hierarchy is *knowledge* that Ackoff defines as know-how that can be obtained through training or instructions from someone who possesses it (Ackoff, 1989; Rowley, 2007). Literature also defines the term "knowledge" as a concept with multiple layered meanings (Polanyi, 2009; Habraken, 1997; Schön, 1987). Therefore, knowledge tends to be addressed via distinctions between its different types, whether it is between declarative and procedural knowledge (Ryle, 2009), or between explicit and tacit knowledge (Polanyi, 2009). Tacit knowledge is formed by the experience of individuals. This type of knowledge is expressed via evaluations, attitudes, points of view, commitments, motivations, and similar forms of human actions. However, on the practical level such as in architecture, many experts fail to articulate their knowledge, abilities, decision process, and conclusion deduction. In a professional context, there is a notable difference between the knowledge base, i.e. the formal and codified domain expertise claimed by a profession (Habraken, 1997), and the practitioner's 'knowing-in-practice', which as Schön (Schön, 1987) indicated, is greatly implicit and learned by engagement.

Regarding architectural design, there is a discussion of whether architectural knowledge is specific and requires unique treatment in contrast to other fields of knowledge. According to Lawson (Lawson, 2018), design education is different compared to other major learning approaches. Lawson argues that schools of design tend to follow a very similar pattern grounded in the traditional master-apprentice model; students working in the studio on limited yet realistic design projects are tutored and supervised by designers with more experience (Lawson, 2018; Heylighen *et al.*, 2007a). CB de Souza discusses that the knowledge associated with the architectural design of buildings is mainly *constructivist*, it is a knowledge that comes from experience (Souza, 2012). This exceptional cultivation of knowledge-through-practice in architecture has led to the lack of formal codification of a common knowledge-base, as practiced in other professions, such as law or medicine (Habraken, 1997). It appears that the architectural knowledge-base is mainly implicit and embedded within the architects' reasoning and creativity, which in turn leads to challenges in incorporating knowledge management theories and methodologies that have gained widespread acceptance in other fields (Heylighen *et al.*, 2007a). A key challenge here is that the professional language of architecture is not easy to define, as it can certainly be seen on the one hand as a technical language, the language of civil engineers, and on the other hand as the artists' specialized language (Kuznecova and Löschmann, 2008). Moreover, as Habraken convincingly argues, architecture lacks a common lexicon of general recognition and significance, for architects have an alarming tendency to coin personal vocabulary and rename elements on a regular basis (Heylighen *et al.*, 2007a; Habraken, 1997).

2.2. Building design decision-making process

The building design process is challenging to be captured and comprehensively documented due to so many reasons, most of which relate to the nature of design problems. Design problems are identified as 'wicked' problems by Rittel and Webber (Rittel and Webber, 1973), which makes them basically ill-structured. Thus, according to Rittel and Webber (Rittel and Webber, 1973) dealing with wicked problems, one should see the concept of planning as an argumentative process in which a vision of the task and solution coevolve progressively among the participants as a result of continuous reasoning and critical debate. Furthermore, Gero introduced the Function-Behaviour-Structure (FBS) ontology as a design ontology to describe all designed artifacts and then based on that the FBS framework and later the situated FBS (sFBS) framework to describe all designing processes (Gero and Kannengiesser, 2014; Gero, 1990). Another interesting perspective on design decisions is the naturalistic decision-making theory, which views decision-making as a continuous flow of acts that work toward a set of goals rather than as discrete choices (Klein *et al.*, 1993). Design problems are listed as one of the domains where naturalistic decision making may be found; where problems and goals are poorly structured and shifting; a dynamic and uncertain context in which the decision-maker must deal with incomplete and vague information; and situations in which a series of choices and events rather than a single decision must be made (Klein, 1993; Klein *et al.*, 1993).

Using BIM (Building Information Modelling) methodology, complete digital representations of built facilities are created as building information models and utilized for storing, maintaining, and sharing information (Borrmann *et al.*, 2018). The Level of Development (LOD) concept describes the progressive refinement of the geometric and semantic information by providing definitions and illustrations of BIM elements at different stages of their development (Janson and Tigges, 2014b; BIMForum, 2019). Even though BIM is potentially altering the way architects, engineers and contractors conduct their work and daily jobs, it's still early in its implementation and the construction industry's fragmentation prevents BIM from becoming completely adopted and more widely used (Borrmann *et al.*, 2018, 2021).

2.3. The importance of early design stages

Building design as a problem-solving process starts with the customer's demands, which are then converted into a design job. However, requirements or even an RFP are not the same as defining the design problem, and the designer must interpret the requirements in a meaningful way (Harfield, 2007). Furthermore, it is not only the clients' wishes and demands that form a building design, but also numerous regulations, constraints, and technical aspects. The most important phases of the building design are the early phases (preliminary and conceptual phases), where fundamental and crucial design decisions are made (Kolltveit and Grønhaug, 2004). The earlier the design stage, the easier it is to change or modify design aspects, whereas, in more advanced phases, it becomes more difficult to change or modify prior design decisions (Steinmann, 1997). The main difficulty during these early phases is the sheer load of design decisions, and the lack of sufficient information and knowledge about the consequences of those decisions (Zeiler *et al.*, 2007).

The BIM methodology substantially enhances the coordination of design operations, simulation integration, and the transfer of building information (Borrmann *et al.*, 2021), however, utilizing BIM during early design stages has its own difficulties. While the information contained in BIM models appears exact and certain, most design aspects and details are uncertain and ambiguous, during the early stages of building design (Abualdenien and Borrmann, 2019). To address this challenge, Abualdenien and Borrmann developed a multi-LOD meta-model (Abualdenien and Borrmann, 2019) for formal specification of maturity levels of building information models, while allowing the explicit expression of potential information vagueness during the early design phase. Abualdenien and Borrmann also presented different approaches and concepts for visualizing the vagueness and uncertainty in building models across different design stages (Abualdenien and Borrmann, 2020b) and for formally analyzing and classifying the geometric detailing of building elements (Abualdenien and Borrmann, 2020a).

Furthermore, to ask for expert opinions about different design aspects (via simulations and analysis), more information and details are required, which are only available in later design phases (Zahedi and Petzold, 2018). Similarly, collaborations and cooperation between multiple domain experts and stakeholders have proven to be essential for achieving a good and optimal design (Zahedi *et al*.). To deal with this problem, Zahedi and Petzold developed a minimal machine-interpretable communication protocol based on BIM to facilitate the workflow and communicate the proposed detailings and their corresponding evaluation results for supporting the decision-making process (Zahedi *et al;* Zahedi and Petzold, 2019; Meng *et al.*, 2020). Matern and König introduced an approach for managing various design variants across multiple planning stages in a consistent digital building model (Mattern and König, 2018). Geyer and Singaravel showed that engineering surrogate models based on components and machine learning (ML) can predict energy demand with the required accuracy in the early stages of design (Geyer and Singaravel, 2018) and with a small prediction gap in comparison to the dynamic simulation approach (Singh *et al.*, 2020).

2.4. References and knowledge extraction from semantic models

The use of references in architecture is considered a recognized method (Gänshirt, 2012) for supporting design, testing ideas, clarifying design parameters, or showing new ways and possibilities. It is a method that supports decision-making. The built and planned models serve as a knowledge base that includes spatial situations as well as solutions for specific architectural expressions. The use of analogies in references is an efficient method for documentation, both in design and in downstream activities. Due to the growing acceptance of the BIM methodology, BIM models are increasingly being stored in cloud repositories. A retrieval system is a prerequisite for effectively managing and using these models. Most commercial BIM retrieval approaches use text-based and keyword-based search strategies that rely on metadata (e.g. keywords, tags, descriptions). Gao et. al. (Gao *et al.*, 2015) presented a concept for a text-based semantic search engine and its prototypical implementation “BIMSeek” to make online BIM resources accessible. Based on the IFC data model (Industry Foundation Classes), a domain ontology was built to encode BIM-specific knowledge in the search engine. By combining both the ontology and local context analysis techniques, an automatic search-enhancement method was integrated to improve search performance. In addition to the textual search, a graphical search is viable; in Inanc (Inanc, 2000) with a 2D graphical search and in Funkhouser et al. (Funkhouser *et al.*, 2003) with a 3D graphical search. Among others, Demian et al. (Demian *et al.*, 2016) presented a combination of graphical and topological search.

The use of graphs in the BIM context for analyzing and extracting information and knowledge has been the focus of various research projects. Langenhan et. al. introduced the concept of semantic fingerprint of buildings to formalize architectural spatial situations and the computer-aided determination of similarity (Langenhan *et al.*, 2013). Furthermore, Ayzenshtadt et. al. designed an extension assistance system based on the distributed AI-based methodology FLEA (Find, Learn, Explain, Adapt) to inform architects and offer solution suggestions on how the current floor plan solution tends to evolve during the design process (Ayzenshtadt *et al.*, 2018; Eisenstadt *et al.*, 2019).

2.5. Case-Based Design (CBD)

A general approach in problem-solving, called case-based reasoning, is carried out by drawing on a previously solved similar problem case (Maher *et al.*, 1995). Likewise, learning from previous design cases and using them as inspirations to solve at-hand problems or to use similar details and information from other building designs are the goal of many researchers in the field of capturing and documenting tacit architectural design knowledge.

Qualitative assessments have been discussed especially in research projects in the field of case-based reasoning (CBR) as mapping procedures defined for classifying and documenting design cases. Individual design situations that are represented by design episodes that correspond to specific design features are well known as episodic case-based designs (Maher *et al.*, 1995). In a more graphical approach, as part of their case-based design (CBD) tool called DYNAMO (Dynamic Architectural Memory Online), Neuckermans et al. (Neuckermans *et al.*, 2002) and Heylighen et al. (Richter *et al.*, 2007; Heylighen *et al.*, 2007b) designed and prototypically implemented "visual keys" for visually indexing design cases and as an access mechanism. These visual keys are used as labels, allowing the user to tag design situations and later search for and access similar cases. Visual keys convey architectural expressions and features. For instance, a visual key can refer to an open-ended grid for the building or to the plan-libre (as introduced by Le Corbusier as a free plan arrangement of non-structural partitions determined by functional convenience) for the spatial configuration. A visual key can also refer to the functionality of the building such as a hospital, or a formal qualification such as symmetry for the arrangement of spaces (Martin *et al.*, 2003; Heylighen *et al.*, 2003). Based on two review papers by Heylighen et al. (Heylighen and Neuckermans, 2001; Richter *et al.*, 2007), some other case-based design (CBD) tools and projects include Archie-II (Domeshek and Kolodner, 1992; Domeshek and Kolodner, 1993), CADRE (Hua *et al.*, 1996; Hua and Faltings, 1993), FABEL (Voss, 1997; Schmidt-Belz and Hovestadt, 1996), IDIOM (Smith *et al.*, 1995; Smith *et al.*, 1996), PRECEDENTS (Oxman, 1994), SEED-Layout (Flemming, 1994), SL-CB (Lee *et al.*, 2002), TRACE (Mubarak, 2004), CaseBook (Inanc, 2000), MONEO (Taha *et al.*, 2007) and Case Base for Architecture-CBA (LIN and CHIU).

2.6. Natural Language Processing (NLP)

Automatically extracting knowledge from unstructured data, such as RFP or building codes, which is written in natural language, is necessary in order to make use of it during the project's life cycle. Natural language processing (NLP) provides the techniques that can provide a computer-readable representation of a natural language text. NLP was leveraged for supporting multiple use cases in the AEC industry. Jung and Lee developed a method that is based on NLP and unsupervised learning to automatically classify the different case studies of construction projects according to their BIM use (Jung and Lee, 2019). Additionally, for supporting in performing an automated compliance checking, Salama and El-Gohary, and Jung and Lee combined NLP with supervised learning algorithms (Jung and Lee, 2019; Salama and El-Gohary, 2016). Moreover, Wu et. al. proposed an NLP-based retrieval engine for BIM object databases, leveraging a domain ontology (Wu *et al.*, 2019) and Lin et. al. introduced an approach for data retrieval from BIM models hosted on the cloud (Lin *et al.*, 2016).

In order to explore and query requirements and regulation documents during the design phases, identifying the semantic text similarity between a natural language query and those documents is necessary. To perform multiple calculations on the natural language, words and sentences from these regulatory documents must be represented in a computer-readable way, typically achieved through a process known as *Vectorization* (Wilbur and Sirotkin, 1992). A vector is a list of numeric values, where the combination of them represents the overall meaning, which makes it possible to measure the semantic similarity represented by the text, where similar words have vector representations that are closer (Wilbur and Sirotkin, 1992). Measuring the similarity between the numeric vectors has performed remarkably well in different domains (Chen, 2020). A key aspect of vectorization is the vocabulary taken into account (the vector space) to generate the vector representations of new sentences or words. The larger the unique words and the dimension of each vector, the better is the resultant vector representation. A typical workflow for performing NLP comprises:

- *Tokenization*: splitting the sentence into discrete units, i.e., singular words.
- *Lemmatization*: converting each word to its original form (i.e., dictionary form or lemma). For example, the lemma of the words *best* and *better* will be the same, *good*.
- *Part of speech (POS)*: the generation of POS tags, for example, identifying if a word is a noun, adjective, etc.
- *Stop Word Removal*: removing stop words, which are tokens that appear with high frequency across the entire document. They typically introduce more noise than signal (benefit).
- *Vectorization*: converting the textual representation into a vector representation. The main advantage of vectorization is that we can measure the similarity between words to resolve confusion with words that have a similar meaning, e.g., external is very similar to outer and exterior.

This paper employs the exact above-mentioned NLP workflow to filter and recommend an applicable set of requirements and regulations for designers during the design process. More details are provided in section 3.3.

2.7. Design Constraints

Current BIM-authoring and parametric design tools maintain the integrity of the design based on the imposed geometric constraints (Zhang *et al.*, 2020; Lee *et al.*, 2006). Domain knowledge includes numerous aspects. For example, if the design is meant to be used for fabrication, a specific set of properties, including material, must be specified. Additionally, good design practices, taking into account the acoustics, circularity, and privacy of the design, pose different kinds of requirements and constraints.

Multiple researchers have investigated incorporating domain knowledge using constraints (Bhooshan, 2017; Bettig and Shah, 2001; Brown and Mueller, 2019). However, these studies have primarily focused on optimizing the geometric design to fulfill specific building performance indicators rather than on capturing domain knowledge in the form of geometric and semantic constraints. The currently available BIM-authoring tools provide the ability to add dimensional and positional constraints. However, the currently available constraints only support the basic use cases, for example, it is not possible to freely assign constraints to property values (for restricting them) or to constrain the connection position and angle of two walls. Most popular BIM-authoring tools, such as Autodesk Revit[1], support aligning element position and dimension to each other using predefined constraints, such as equality constraints[2]. Furthermore, the tools automatically apply other constraints implicitly, such as attaching a wall to a roof. The constraints in these systems are meant to support the design process and handle the most common use cases.

However, when considering constraints from the perspective of capturing design knowledge, designers implicitly apply many additional constraints while trying to fulfill owner requirements and regulations. Typically, constraints can be expressed geometrically on element dimensions, positions, and their topological connections, as well as semantically, demanding a specific value, a list of values, or a permissible range of values. To fill this gap, this paper proposes a meta-model approach for capturing domain knowledge in the form of semantic and geometric constraints. The individual constraints are then assigned to the individual elements and properties.

3. METHODOLOGY

The process of capturing and sharing architectural knowledge with its complexity and dynamism requires the consideration of various aspects. Some knowledge is stored within construction documents or the designed model, yet neither can reveal the constantly changing conditions that actually structure the process of designing. As illustrated abstractly in Figure 1, each construction project is bound to specific site information and boundary conditions, which influence the selected architectural concepts, and then the detailing of the individual elements. For example, the site of a residential building that is close to a highway (where traffic is heavy) or near a school facility, requires careful consideration of the designed facade, especially in terms of noise reduction techniques. On the other hand, a site facing a nature preserve or wooded area fosters using curtain walls or big windows.

Taking into account the project's site information, architects and engineers need to take into account fulfilling owner requirements and building codes (requirements level). All of these aspects are combined with the designers' style and domain knowledge to create multiple concepts covering the different aspects of the design's functionality (concept level). Finally, each of these concepts is implemented in the form of detailed components, their connections, and the constraints bounding them (design level).

Numerous aspects of the design knowledge, including organization of spaces, navigation between spaces, the choice of insulation and material layers, etc., are implicitly embedded into design artifacts. But the design processes, including the assessments of intermediate design variants and corresponding design decisions, are hardly comprehensibly documented today. This type of design knowledge is extremely valuable, as it opens new possibilities for improving productivity and efficiency in architectural building design. Decisions in the selection

---

[1] https://www.autodesk.com/products/revit/overview

[2] https://knowledge.autodesk.com/support/revit-products/learn-explore/caas/CloudHelp/cloudhelp/2019/ENU/Revit-Model/files/GUID-91CBCCF3-66D1-496B-80B3-D893065D1A50-htm.html

and further detailing of variants ought to be recorded and in particular, the reasons why they were made, to ensure later traceability and transferability of design knowledge to other projects. Such knowledge is highly valuable as it provides a solution that combines architectural tacit knowledge, fulfilling owners' demands, building codes, and the various regulations. To capture design knowledge, we propose the following concepts and approaches.

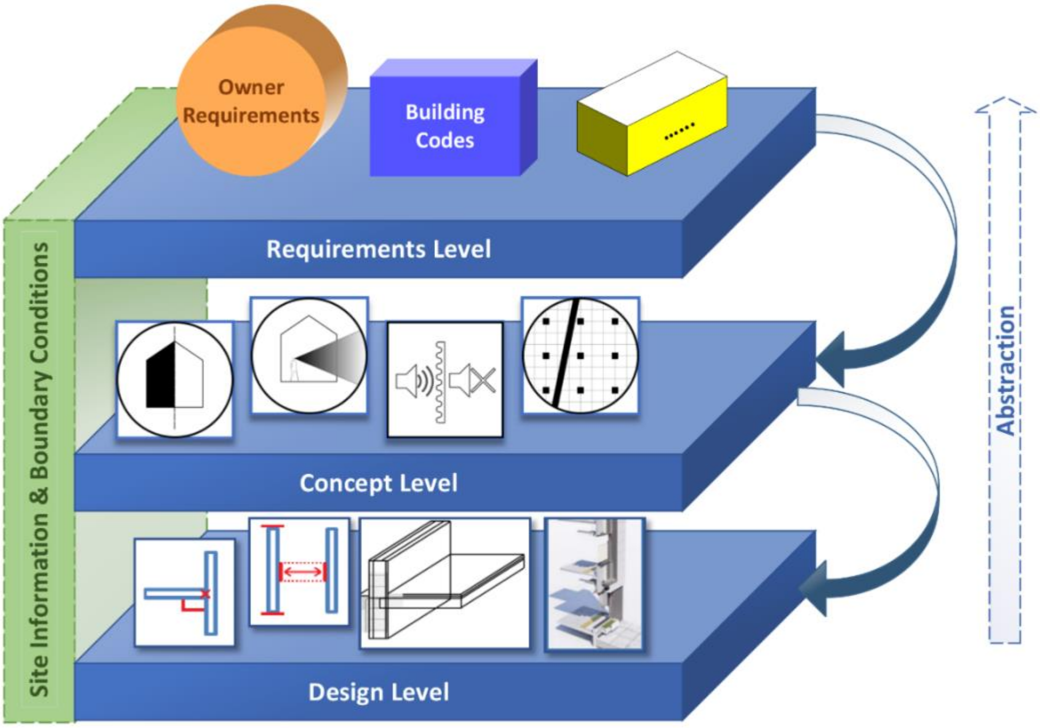


Figure 1: Construction projects' design abstraction levels based on the methodology and introduced concepts of this paper are envisioned. The design process of a construction project takes into account the surrounding boundary conditions, requirements, and regulations in order to apply specific design concepts, followed by design constraints (Abualdenien and Borrmann, 2021).

3.1. Design Episodes and Explanation Tags

One of the solutions for transferring architectural knowledge discussed in the literature is through storytelling (Heylighen *et al.*, 2007a). Stories that are engaging and easy to understand, are especially useful for sharing individual tacit knowledge. Although it may not transfer huge amounts of information, it is a means of catalyzing understanding. In addition to the benefits of using narrative, storytelling is non-adversarial and non-hierarchical, providing an opportune breach in the defensive nature of the creative work that architecture is, where ideas and outcomes are essential in terms of ownership and recognition. Storytelling is not a replacement for rigorous analytical thinking, but it complements our understanding of a phenomenon by bringing alternative perspectives and worldviews into play. Storytelling also allows for multiple issues of importance to be addressed in terms of complexity in architectural design. In addition to stories being direct, easy to read, and entertaining, they respect the intricate relationship of things, making them quite memorable. Therefore, storytelling permits a dense and compact way of communicating complexity in a short time. The stories' outcomes cast ownership onto the reader by connecting the story to their personal experience. The outcome is irrelevant to the fact but relates more to the ideas, processes, decisions, and implications of the interactions demonstrated within the story. The potential of storytelling for capturing and storing the tacit design knowledge is proven effective in the "Building Stories" project, developed and run by Berkeley University in California, with support from some leading architectural companies in the San Francisco Bay Area. During this project, various teams of architectural students, interns, and professionals built and revised stories about some architectural projects that were being designed or had already been built (Martin *et al.*, 2005). With this in mind, in this paper, we introduce the concept of *design episodes (DEs)* to divide and store various pieces and chapters of design. Each DE contains a name, ID, and textual description that explains the designer's intentions and clarification, together with the list of corresponding building elements and spaces that represent this situation. Within the framework of storytelling, we believe that DEs provide the ability to break down the overall design into essential components and features addressing unique project-specific challenges, and thus to effectively record and manage innovative and newly created design knowledge. More demonstrative examples for DEs are discussed in section 4.

Meanwhile, what are the expectations of architects who are willing to document and justify their design decisions while designing? The thought process of designers is both graphical, as it works through, in, and with images, as well as textual, e.g. engineering numbers and linguistic words, creating a silent dialogue using elements similar to all other visual artists (Cross, 1982). Discarding, selecting, and further detailing architectural design decisions and variants depends not only on objective (quantitative) criteria but also on subjective (qualitative) criteria. In addition to building model and quantitative criteria, qualitative and descriptive (sometimes episodic) assessments and evaluations are necessary for documenting the selection of variants in order to make the decisions made and their justifications, e.g. the architectural quality, comprehensible and to support the interpretation of the architectural solution. The goal is to store and document design decisions and variants selection without significantly interrupting the design process. With this in mind, a collection of so-called *Explanation Tags (ETs)* is offered to the architects to choose from while designing inside a BIM authoring tool, enabling them to argue and justify their design decisions by assigning these ETs to building components and spaces or to their specific attributes. More clarifications on how to use the ETs will be discussed in sections 3.4 and 4. This open-ended collection aims to represent a graphical codification of architectural terms, inspired by major theoretical architectural publications and empirical guidelines. It is important to mention that this collection of ETs is not limited to what is presented in this paper as a set of examples and can be extended by new users and domain experts based on their needs. Furthermore, it should be noted that the collection and provision of these ETs are not the main focus of this paper, but rather the framework in which these tags could be expanded and offered to the designers is of importance and among the contributions of this paper.

Our first selection of ETs was based on SNAP (Systematik für Nachhaltigkeitsanforderungen in Planungswettbewerben) (Fuchs *et al.*, 2013). SNAP was developed under the Federal Ministry of Transport and Digital Infrastructure in Germany. Likewise in Switzerland, the Swiss SNARC methodology "Systematik zur Beurteilung der Nachhaltigkeit von Architekturprojekten für den Bereich Umwelt“ (Schweizerischer Ingenieur- und Architekten-Verein, 2004) was developed for use in competition procedures. We then expanded our collection of explanation tags using some other related work and architectural literature (Neuckermans *et al.*, 2002; Janson and Tigges, 2014b; Janson and Tigges, 2014a). Each Explanation Tag (ET) is represented with an icon and stored together with an ID, name and textual description, and sometimes graphical explanatory examples, such as photos, plans & sections, 3D models, and partial BIM models. Using NLP techniques and domain-expert-knowledge, the tags are also cross-connected via meta-data markers (in the back-end of the system) through a series of overlapping meanings such as synonyms, antonyms, complementary, related, or associated meanings, which will be used for suggestions and recommendations to help the architects upon using them. Since it is almost impossible for us to collect all the terms and criteria for the whole architectural domain, due to its complexity and variability for different projects and experts, only an exemplary collection of ETs is presented and used in this paper. However, our system design guarantees extensibility, and new ETs can be added to this collection. The open-ended aspect of our system allows some experienced and knowledgeable users to create their own ETs and enhance the vocabulary of architectural terms.

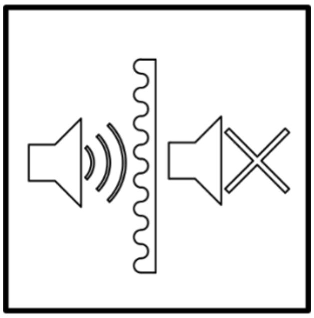
Our collection of ETs along with their definitions and in some cases, best practice suggestions, and examples for them are in Appendix A (Explanation Tags) at the end of this paper. This collection contains both subjective (qualitative) and objective (quantitative) design criteria. To differentiate between these two categories, the icons for the subjective ones are enclosed inside a circle frame, whereas the icons for the objective ones are framed inside a box. Table 1 shows two of these ETs. Once again, it is crucial to note that this collection of ETs, in Appendix A, is by no means complete and is subject to improvements and enhancements. However, the introduced concept of *Explanation Tags* and the presented framework in which new ETs could be added guarantees the adjustability and expansibility of our system, and is of importance to this paper and among its contributions.

The way our concept for documenting design decisions works will be discussed in greater detail using some demonstrative examples and use cases. In a nutshell:

- The designers can split the overall design into multiple design episodes and explain their intentions and solutions for different design challenges using storytelling techniques.

- They can assign explanation tags to different building components and spaces or their specific attributes to mark and clarify the reasons and goals for different design decisions graphically and in more detail.
- They can set up constraints, which will be explained next in section 3.2, to make sure some design aspects and decisions will be kept intact and unchanged as the design process moves forward and the design model is further developed.

Table 1: Two of the Explanation Tags related to subjective and objective criteria

Topic	***Explanation Tag***	***Description***
Comfort		A sense of physical contentedness, which comes from many physically measurable conditions, such as light intensity, atmospheric humidity, temperature, air exchange, and noise intensity. Alongside the physical measures, a spatial situation also interferes with comfortableness, including room size, spatial proportions, and gestures.
Sound insulation		Unwanted noise and acoustic conditions affect well-being and can affect health. By appropriate conceptual and structural measures, pleasant acoustic conditions are to be established. This applies equally to the structural sound insulation against external noise and noise pollution between different rooms. **Excellence rating:** favorable orientation of vulnerable areas; favorable orientation of private open spaces; structural noise protection measures considered; no conflicts of use. (Fuchs *et al.*, 2013)

3.2. Design constraints: Multi-LOD Meta-Model

Explicitly specifying design requirements and constraints could support documenting design intentions and decisions, especially during early design stages. Additionally, such constraints could be checked to verify and confirm that design decisions are still being maintained. In this paper, we propose two kinds of constraints, geometric and semantic. Figure 2 illustrates the concept behind the geometric constraints. Each face of the individual elements is represented by its center point, which is used to describe the connection constraint among multiple elements. The constraint can refer to the face center point in addition to a directional anchor (e.g., top, left, etc.) and a numerical padding to provide the necessary flexibility. To describe the spatial constraint between two elements, the distance and the degree are captured. On the other hand, semantic constraints are focused on specifying the permissible property values in multiple ways (explained in detail in this section).

In practice, it is necessary to explicitly specify which information is reliable and estimate the accuracy of the unreliable information at a specific LOD; an LOD is depicted as a milestone for making design decisions. Consequently, precisely defining the LOD requirements while incorporating their uncertainty improves the quality of the collaborative process among the disciplines.

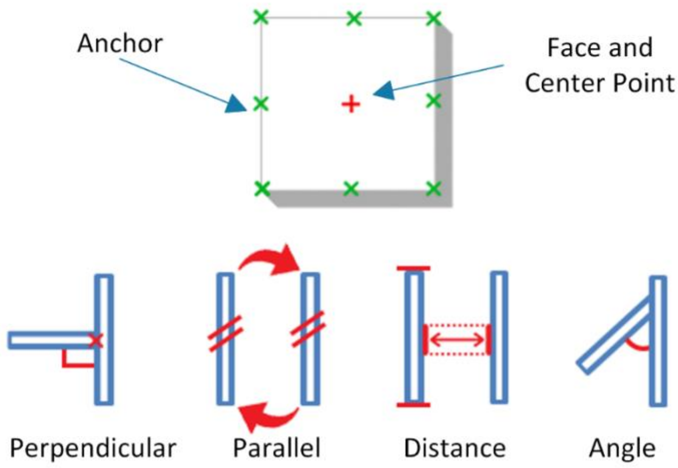


Figure 2: The proposed approach for capturing spatial constraints between building elements, using the distance and angle between the elements as well as vertical and horizontal anchors and padding.

Managing information on multiple LODs requires both representing the building elements on different LODs as well as providing the ability to specify the required information on each LOD in a formal way. The multi-LOD meta-model fulfills these requirements by supporting the following activities (Abualdenien and Borrmann, 2019):

- Formal specification of the overall information requirements at a particular design stage.
- Formal specification of the individual elements' LOD definitions.
- Formal incorporation of the potential vagueness.
- Representation of the building models' instances at different design stages.
- Verification of building models consistency across the design stages, i.e., ensuring that the decisions made in one stage are respected in the subsequent stage.

The meta-model introduces two levels: data-model level, which defines the component types' requirements for each LOD, and instance level, which represents the actual building components and their relationships. To ensure the model's flexibility and applicability, its realization is based on the widely adopted data model Industry Foundation Classes (IFC). The IFC model specification is an ISO standard, which is integrated into a variety of software products (Liebich *et al.*, 2013). More specifically, entities from the meta-model are linked to existing IFC entities and then provide extensions, including component types, properties, relationships, and geometry representation. This makes it possible to attach requirements, vagueness, constraints, and documentation.

In more detail, each component type is linked to an IFC type, IfcColumn as an example, and associated with multiple LOD definitions. An LOD definition consists of geometric and semantic requirements, specifying the required geometry representation and properties. The details of each property are determined in addition to the permissible vagueness. In terms of vagueness, a property can be assigned to a vagueness type (classification or probability distribution), a maximum vagueness percentage, and whether the vagueness values are expected to be a range. The vagueness values at the instance level are automatically generated from the vagueness definition specified at the data-model level. For example, in case the vagueness type is a probability distribution, the vagueness percentage is 4%, and the attribute value is 250 cm, the vagueness values are generated to form a range of ±20 cm. Moreover, at the instance level, it is possible to increase the limitation of the range values, such as to be between -5 and +7 cm. A comprehensive explanation and evaluation of the multi-LOD meta-model approach are available in (Abualdenien and Borrmann, 2019).

The constraints concept is implemented in the meta-model as shown in Figure 3. Accordingly, in this paper, the meta-model design is extended to incorporate the documentation of design decisions and constraints. In more detail, the data-model level is extended to allow defining design knowledge in three forms, *explanation tags* (discussed in Section 3.1), *design requirements* (which can contain the RFP requirements or building code provisions), and *design episodes* (also discussed in Section 3.1). At the instance level, ETs, requirements, and DEs can be assigned to describe components, property values, and constraints. This way, the reason behind using a particular property value or constraint is documented. The meta-model supports two main constraint types: *SpatialConstraint* and *PropertyConstraint*. The *SpatialConstraint* comprises two children: *DistanceConstraint* and *AngleConstraint* for describing the spatial constraints between multiple elements. Each of these spatial constraints is assigned to a vertical and horizontal anchor as well as four padding values. In the same context, the *PropertyConstraint* allows limiting a reference property with a specific value (e.g., *length <= 2m*) or the value of one or more properties (e.g., *wall1.length = wall2.length*).

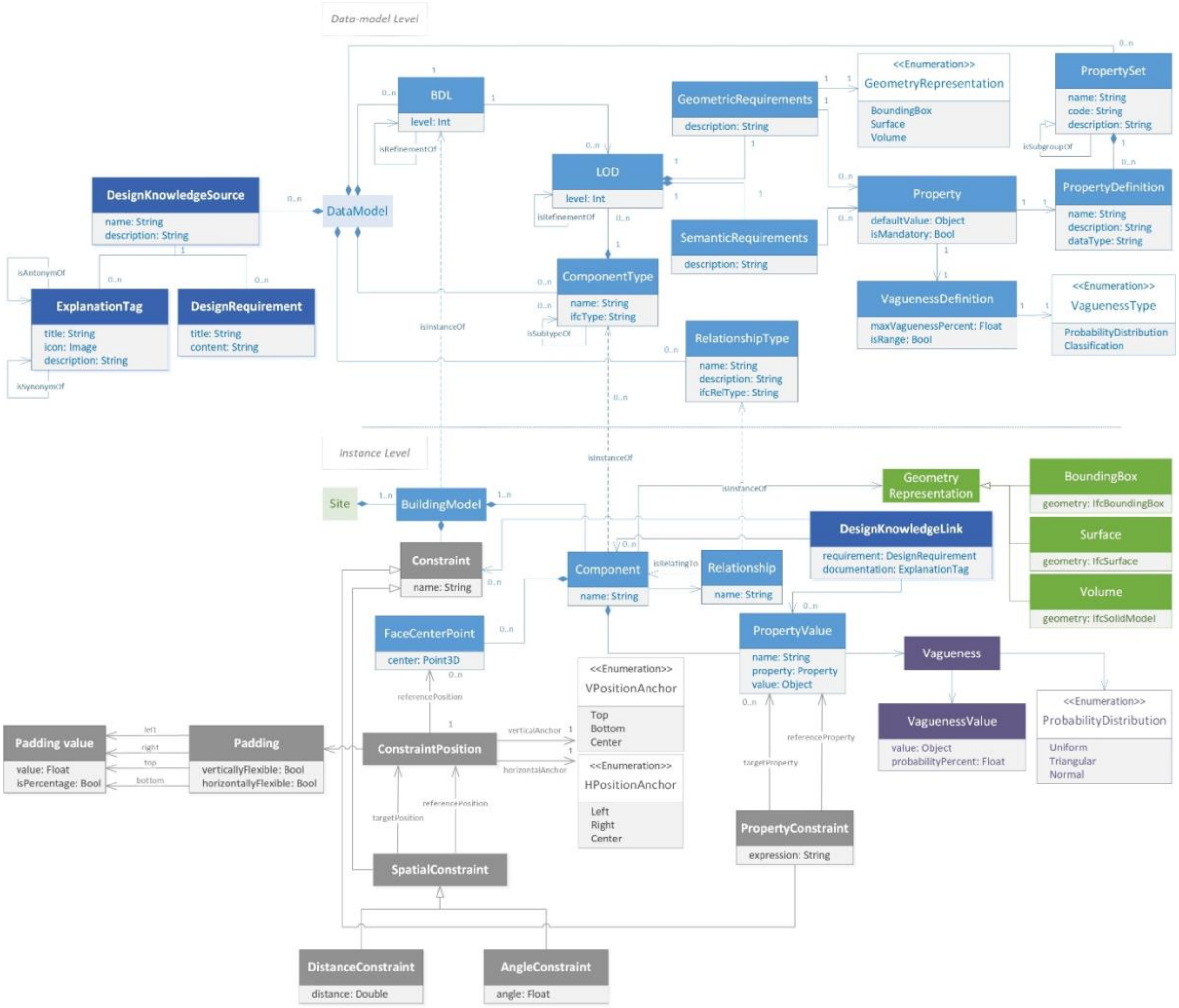


Figure 3: Multi-LOD meta-model (UML class diagram): describing design requirements, knowledge at the data-model level, and representing building elements, including properties uncertainties, constraints, and documentation at the instance level. The purpose of color-coding the boxes is to be able to distinguish between the entities that belong to knowledge, requirements, constraints, geometry, and vagueness.

While constraints are mainly used to maintain design decisions throughout the design phases, explanation tags and design episodes are largely used for documenting and explaining the design decisions as comprehensively as possible. To use an analogy from software programming and design, constraints in our concept are frameworks and blueprints to keep the further detailing and maturation of design decisions in line with previously discussed and decided fundamental decisions, whereas, using the same analogy, ETs and DEs are like commenting the code while programming so that it would be understandable later on.

3.3. Linking Owner Requirements, building codes, and Design Episodes to design decisions using natural language processing (NLP)

Owner requirements, building codes, and design episodes' descriptions are in plain natural text. However, typically, these documents are the reason behind many of the decisions that are made, such as parameters' values or even constraints. Therefore, in this section, we present an approach for extracting these requirements using NLP techniques and for storing a link between these textual definitions and the different elements, their properties, and design constraints. As shown in Figure 4, first, the natural text is preprocessed by organizing it in a tabular format, providing a clear definition in each row. In this research, each row includes a specific building code provision along with its section and chapter titles. Then each row of these requirements is processed using NLP techniques, including tokenization, lemmatization, part of speech, and vectorization. Figure 5 demonstrates an example of processing a rule from the international building code into tokens, then lemmatization, part of speech, and finally the vector representation (which represents every row in a vector space of 300 dimensions). In this paper, we use the open-source NLP neural network spaCy (Honnibal and Montani, 2017), which offers state-of-the-art accuracy in multiple languages (Colic and Rinaldi, 2019). We use the pre-trained large model of spaCy, which includes over one million unique vectors (SpaCy, 2021).

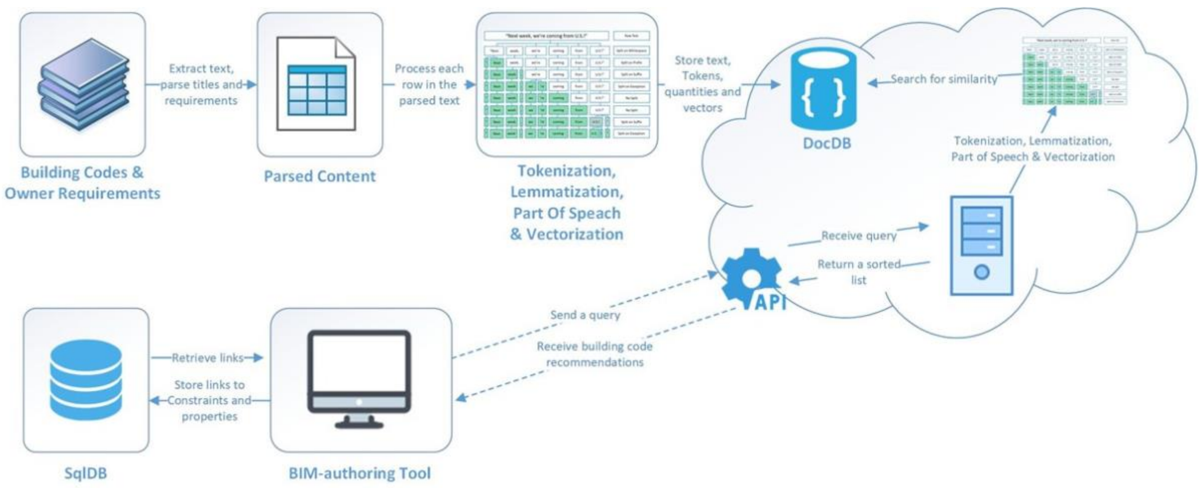


Figure 4: NLP integration approach: the incorporation of NLP during the design process to facilitate querying and linking the individual requirements to the different building elements and their corresponding properties.

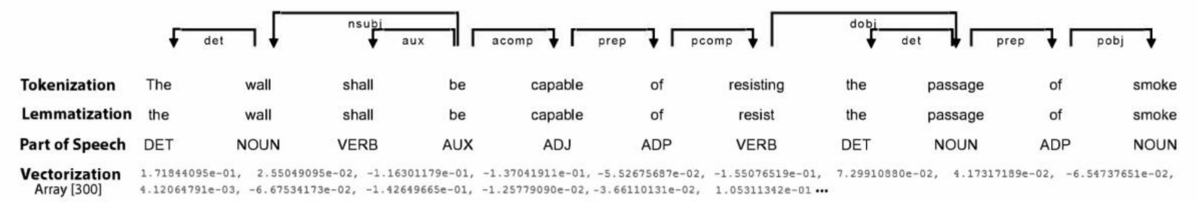


Figure 5: NLP processing example: a rule from the international building code is processed through multiple steps, tokenization, lemmatization, and then the extraction of POS tags. Finally, a vector representation of the complete rule is generated to support comparing rules for similarity to a search query.

The original text as well as the processed content is stored in a document database for future query and use. Afterward, from the BIM-authoring tool, users can query the stored requirements and link a specific requirement to one or multiple properties, or to existing semantic and geometric constraints. Going into greater detail, the BIM-authoring tool communicates with a server through a REST API and sends a query. Then, this query is also processed using the same NLP techniques and compared with similarity to the vector representation available in the document database. According to the state of the art in NLP (SpaCy, 2021), the cosine similarity is the most popular similarity measure when comparing vector representations. Next, the top 10 requirements, sorted by their similarity percentage, are displayed to the user in the BIM-authoring tool.

3.4. Proof of Concept

This section discusses an introduction to the implementation part as proof of concept, followed by three demonstrative use cases in section 4 to illustrate exactly how our concepts and implementations work together. The presented approach is implemented as a plugin inside Revit[3]. When the user selects one or multiple elements, the plugin will display their properties as well as possible spatial constraints, including their corresponding distance and angle. For each item of information shown, the user can add constraints according to the concept introduced by the meta-model (Section 3.2). Figure 6 shows an example of two staircase walls. The lock icons indicate whether a constraint is added or not. Spatial constraints are added here, where the elements must be always *Parallel* to each other, which is described by a distance and an angle of zero degrees. Additionally, the length property of this particular wall is constrained within a specific range and linked to be exactly the same length as the other wall.

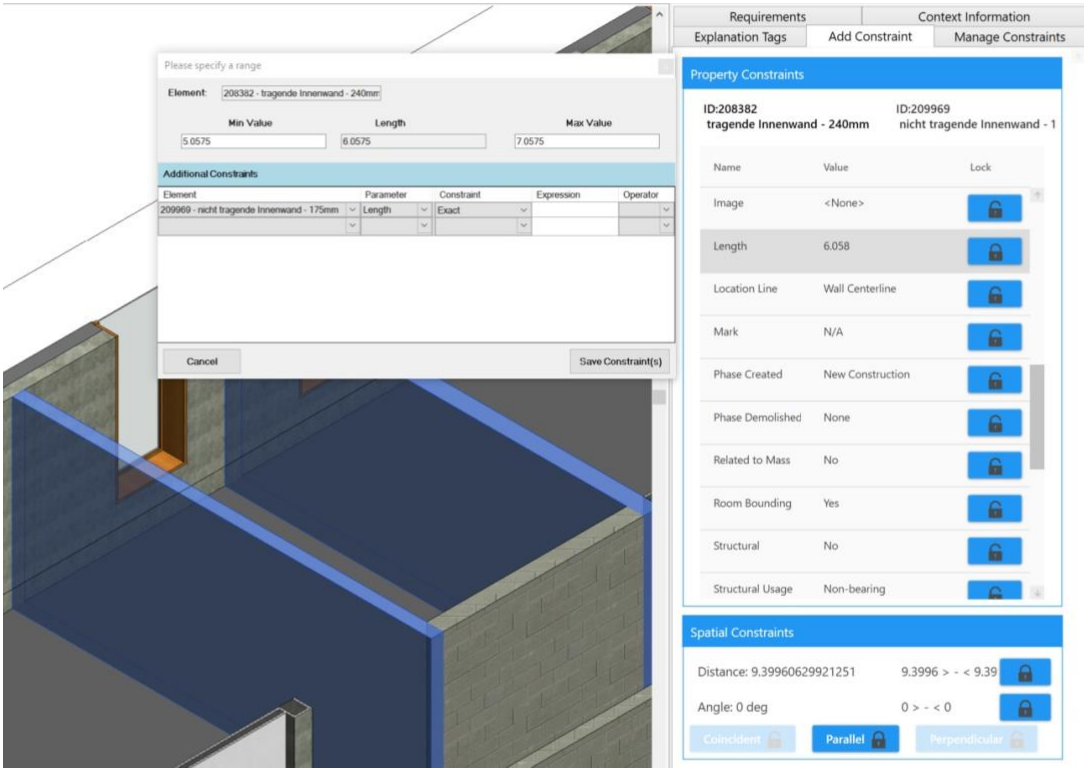


Figure 6: Revit plugin prototype: an example of adding spatial and semantic constraints on two walls of a staircase.

Similarly, the user can assign one or more explanation tags to the selected elements or their individual properties. Figure 7 demonstrates the concept on a load-bearing wall that is bounding a server room. Two tags were assigned to the element: (1) *Sound insulation*, describing that this is an important characteristic for avoiding the workspace disturbance, and (2) *Safety & Security*, raising the consideration for fire-safety regulations or electrical hazards. On the other hand, the *Functionality* tag is assigned to the properties *Length* and *Room Bounding*, and the *Material* tag was assigned to the *Structural Usage* property, highlighting their importance for providing efficient management of the space as well as serving the intended functionality expected from this particular element (all tags are described in the appendix in detail). Furthermore, the process of assigning ETs to BIM elements or their individual properties is identical for all objects, spatial or physical the same. Finally, to document the design according to its fulfillment in terms of requirements and to store a particulate DE, the *Requirements* tab facilitates querying the document database with natural text with the help of NLP. When a query is entered, it is then sent to

[3] https://www.autodesk.com/products/revit/overview

a server, where it is processed and compared with the requirements database in terms of similarity. The results ordered by similarity are then displayed to the user.

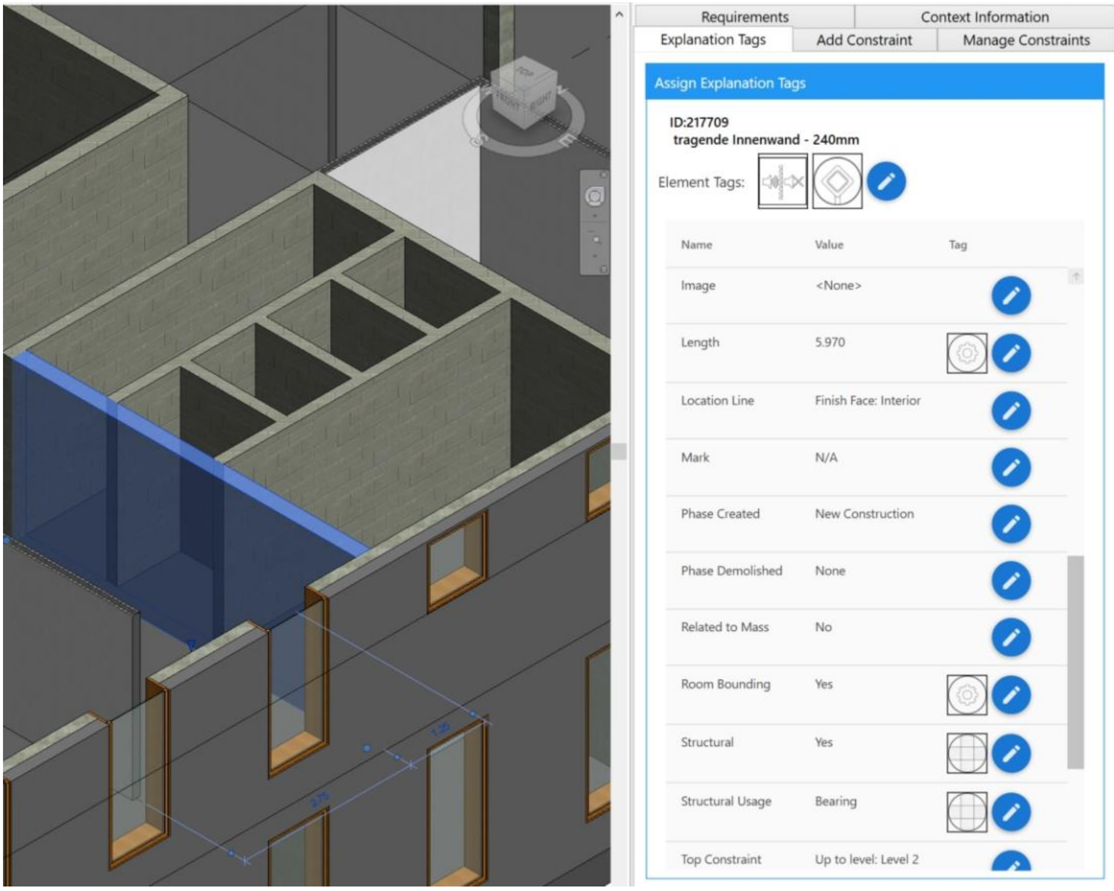


Figure 7: Revit plugin prototype: an example of adding explanation tags to a load-bearing wall that is separating a server from the working space.

Figure 8 shows an example, where a query with walls of exit stair is entered for searching the international building code. Additionally, the building occupancy and use was assigned to *Office* and also the building code provisions with numbers were given a higher priority. Accordingly, the returned results are mainly concerned with the *Means of Egress*, stairs role for occupancy, and fire safety aspects, which is compliant with the requested query. The results panel shows the stored requirements natural text with the nouns highlighted to help the user identify which entities and properties this code is describing. Additionally, there are two additional tabs, one lists the entities/nouns and the other quantities, for example, 60 feet (18,288mm).

Furthermore, as shown in Figure 8, the user can link a particular requirement to specific properties or constraints. Once the user clicks on the open lock icon, a dialog will pop up showing the selected elements and listing the corresponding properties and constraints. At this point, the user is capable of assigning the building code to one or multiple values. This kind of linkage provides additional reasoning for the corresponding values, which designers could refer to when they consider different values. To demonstrate the performance of the developed approach, a screencast was captured and published online[4].

[4] https://youtu.be/tdT1rMddzgU

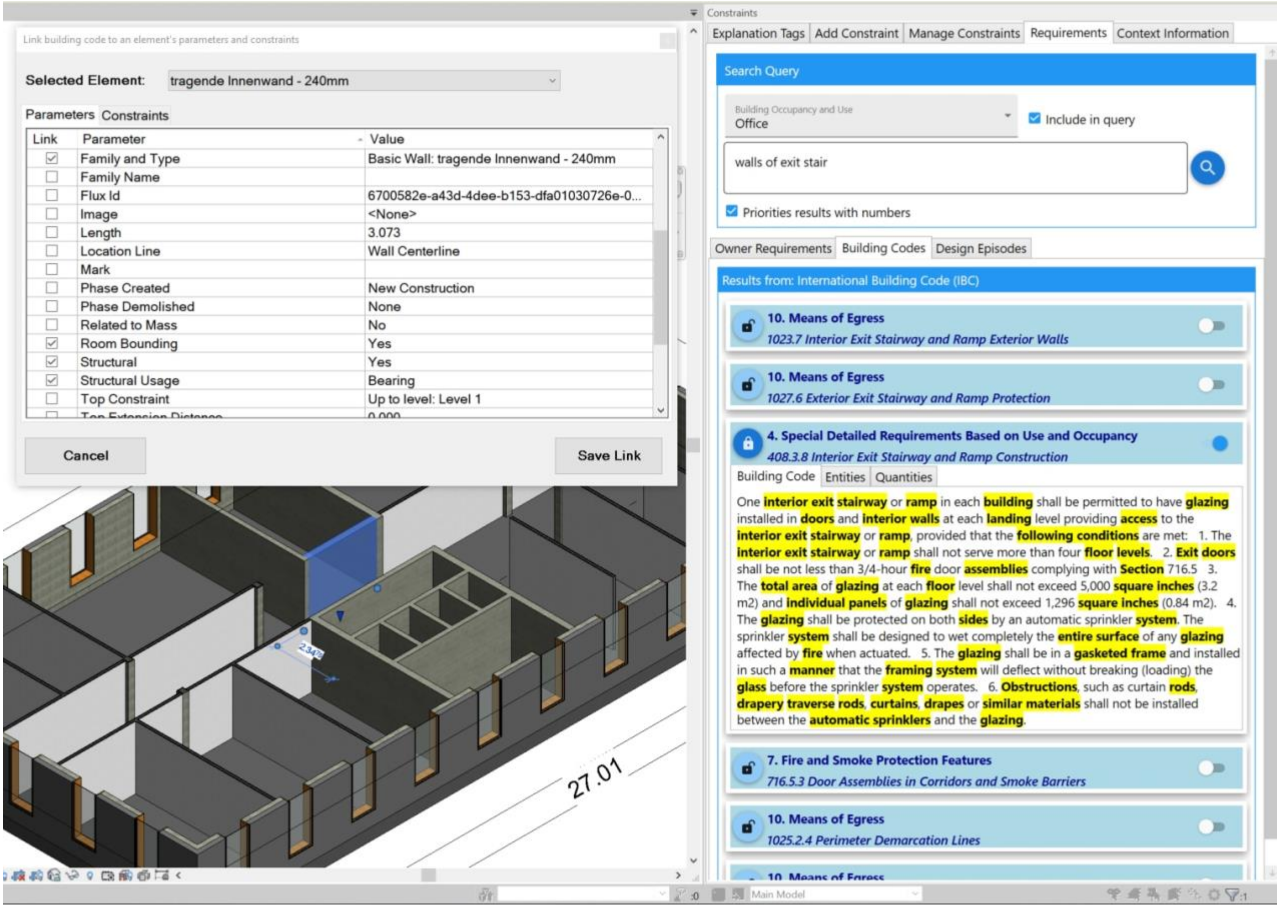


Figure 8: Revit plugin prototype: an example of querying the international building code and linking a rule to a specific wall and its properties.

4. DEMONSTRATIVE USE CASES

This section provides three different use cases, two of which are real-world building projects, to demonstrate the use and applicability of our proposed concepts and approaches. The first use case is based on our own hypothetical design to which we applied our approach and concepts during development. The other two use cases, however, are real building projects that are analyzed and used for our purposes, in terms of the intentions of the designers and the arguments for their design decisions, after the design is complete and they have already been built.

4.1. Use case no. 1 – Open Living and Dining Room

The first use case demonstrates an example for a design episode where the following paragraph could be viewed as the episode description where the designer has written to explain the design's intent.

"In this big living room, the intention is to preserve openness and transparency, while separating the dining area from the living area (which could also be used as a TV room). Clear visual contact between the two sub-spaces is another goal. To achieve that in this floor plan, elevation is used as means of space division and transition, while conserving the continuity and transparency of the two inter-connected sub-spaces. This way, the dining area is separated from the living area inside the (big) living room. The aim is to create a virtual division of spaces while preserving the continuity of the one big living room, which provides a sense of openness and transparency.

On the other hand, the use of an exposed-brick wall in this floor plan presents a personal style in the design, which contributes to the aesthetics or pleasing qualities of design in visual terms. In this case, an exposed brick wall brings an appealing contrast to the other white walls and imposes a warm atmosphere and a tasteful transition into the living area. This will also enhance the acoustics in the living area."

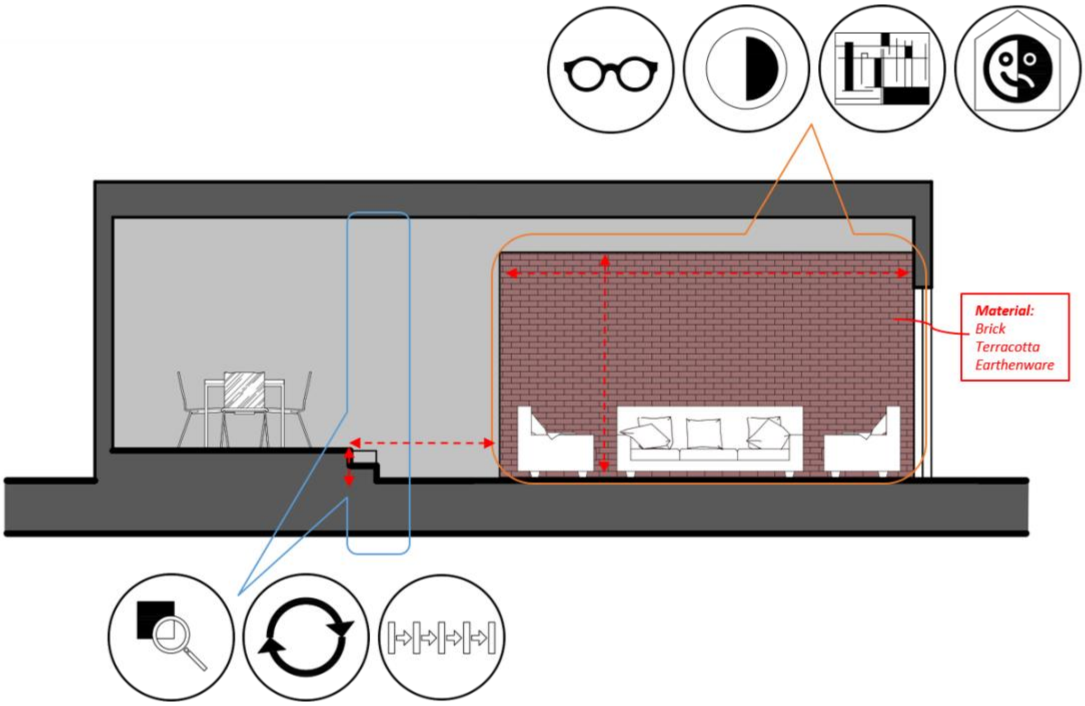


Figure 9: Use case no. 1 - showing the ETs of Transparency, Continuity, and Transition on the elevation steps and Personal Style, Contrast, Aesthetics and Atmosphere on the exposed brick, together with Material and Dimensional constraints for both

To document and communicate the design intentions for other project participants in a more graphical way, multiple ETs can be assigned to different components, as displayed in Figure 9. Two room labels for the dining area and living area (or the TV area) can separate the two sub-spaces. Multiple ETs, e.g., *transparency*, *transition*, and *continuity* of space in the overall living room, describing the openness, can be attached to the elevation of stairs between the two areas. The ETs can be then interpreted into geometric and semantic constraints to document the design in more detail. Accordingly, the proportion of each area can be restricted with dimensional constraints. Moreover, the elevation between both areas can be represented by a minimum height and number of steps that could keep the separation between the spaces tangible and at the same time keep them open to each other. On the other hand, labeling the exposed brick wall with ETs such as *aesthetics*, *contrast*, and *acoustics* will document the design rationale for this specific wall. The finish material layer of this particular wall influences the aesthetics greatly. The architect in this case could add a constraint for the permissible material layers, e.g., *Brick*, *Terracotta*, *Earthenware*, as well as their thickness.

4.2. Use case no. 2 – Concrete House by Carl-Viggo Hølmebakk in Norway

This use case is developed according to a plan from the *Concrete Lake House* by Carl-Viggo Hølmebakk (*Concrete House - Carl-Viggo HAS*, Stange, Norway, completion in 2015; *Carl-Viggo Hølmebakk AS*, founded in 1990). The following design episode is a summary of Mr. Hølmebakk's opinion about this design taken with his permission from his website (*Concrete House - Carl-Viggo HAS*, Stange, Norway, completion in 2015).

"Although the grand view played an important role in the design, the facade is not fully glazed, but rather "masked out" with varying openings that are positioned and sized with the treatment in mind of natural light, exterior views, and the intended use of interior spaces. Spaces could span two floors, and openings for daylight and views could be tailored to different rooms and situations. The load-bearing in-situ cast concrete also allowed for compelling constructions both in the exterior and in the interior, enabling cantilevering of staircases, roofing, terraces, galleries, etc. Exterior and interior staircases connect the different floors and different areas of the house. This adds to a complex pattern of spatial sequences and movement within a rather rationally executed organization: All living areas and bedrooms face the view, and are distributed over three floors. Secondary functions, such as bathrooms, lavatories, laundry rooms, etc., are located in the rear end of the house, where the facade is relatively

closed. Several west-facing terraces protrude from the building, furthering the living spaces' relationship with the water and the view."

In this case, as is demonstrated in Figure 10, using ETs and constraints would be valuable for justifying and explaining the architectural concept and design intention. A special aspect of this design is the seemingly random distributed openings and windows on its facade that create the feeling of complexity and dazzle, which is best explained by using the *complexity* ET along with position and dimension constraints. However, the interior has a simple three-story layout with a rational organization that puts all the secondary functions at the rear of the house, while all the living areas and bedrooms have a great view. Describing this arrangement of spaces with the *simplicity* ET will enhance the design documentation. This house is a perfect case study for making a series of openings that bring in different angles of natural light and provide comfort for its residents. The architect here leverages the windows to selectively frame composed views from different perspectives and angles, which can be labeled using the *Comfort* and *View* ETs. This use case also shows the use of skylights to bring in natural lighting and solar gain to heat the room and foster the feeling of coziness when the sun shines. These windows could be tagged with *daylight* or natural lighting. Some small windows are used as ventilation panels, whereas, in another plan, an eccentric window is used to bring a well-diffused light into the bedroom, allowing the tenants to see the sky while in bed. Such a window could be tagged with *view*, *natural lighting*, and *comfort*. Each window has a location and a design with a unique intention in mind, one that is hard to capture in the regular design method but it could be done in our approach by adding constraints for the exact *position* and *dimensions* of each window. As illustrated in this plan, by using blended spaces and down-drops in some areas, the architect creates high ceilings and large dimensions and proportions, which ultimately creates the sense of immensity, spaciousness, and vastness for its inhabitants, with quality similar to that of a cathedral. This could be labeled using *Immensity* as an ET.

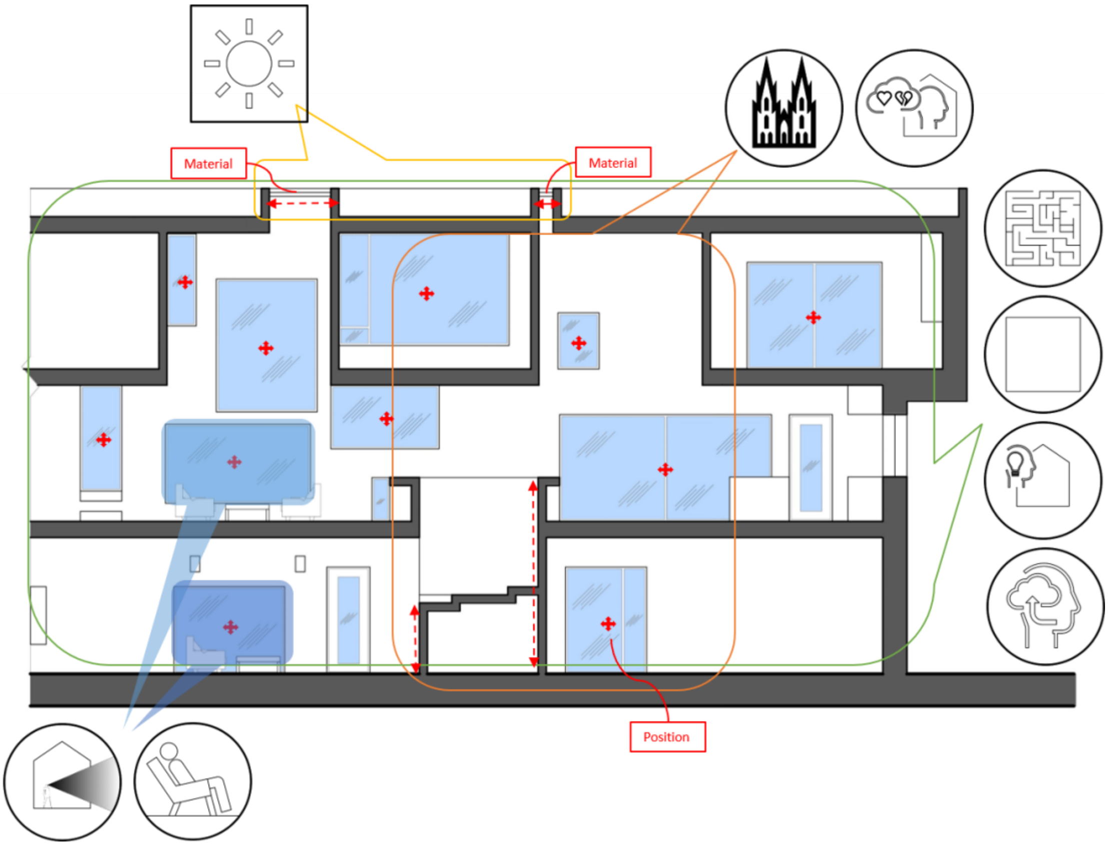


Figure 10: Use case no. 2 - recreated based on the facade section of the Concrete House by Carl-Viggo Hølmebakk (Concrete House - Carl-Viggo HAS, Stange, Norway, completion in 2015) illustrating the explanation tags (ET) for Daylight (solar gain) on the top two ceiling windows, the ETs of Immensity and Expression for the blended spaces, and high down-drops in the middle, the ETs of Complexity vs Simplicity, Concept, Experience, Comfort and View for the layout and organization of spaces and openings, together with the constraints for material and position of the windows

4.3. Use case no. 3 - Tausendpfund building in Germany

The Ferdinand Tausendpfund building in Regensburg is an office building erected at the end of 2016, which consists of three different exterior wall constructions. The building has a first floor and two upper floors with a gross volume of 3950 m^3, a gross area of 1290.5 $m^{2,}$ and a window-to-wall ratio of 25%. The building does not have a basement, which is why the floor slab, the exterior walls, and the roof form the thermal building envelope. In the building itself, all zones are considered to be heated to normal temperatures (Vollmer *et al.*, 2019).

The application of ETs is shown in Figure 11, whereas in this design, structural elements are mostly put in the outer walls or the core with vertical circulation and services in the center and only a few columns are left elsewhere, which creates *spatial efficiency*. This was done according to the owner's requirements for making it possible to flexibly use the building design for both occupancy usages, as an office or residential building. This building is also thoughtfully designed considering criteria such as *accessibility* and *barrier-free access*, *external space quality* and *spaces for social integration*, etc.

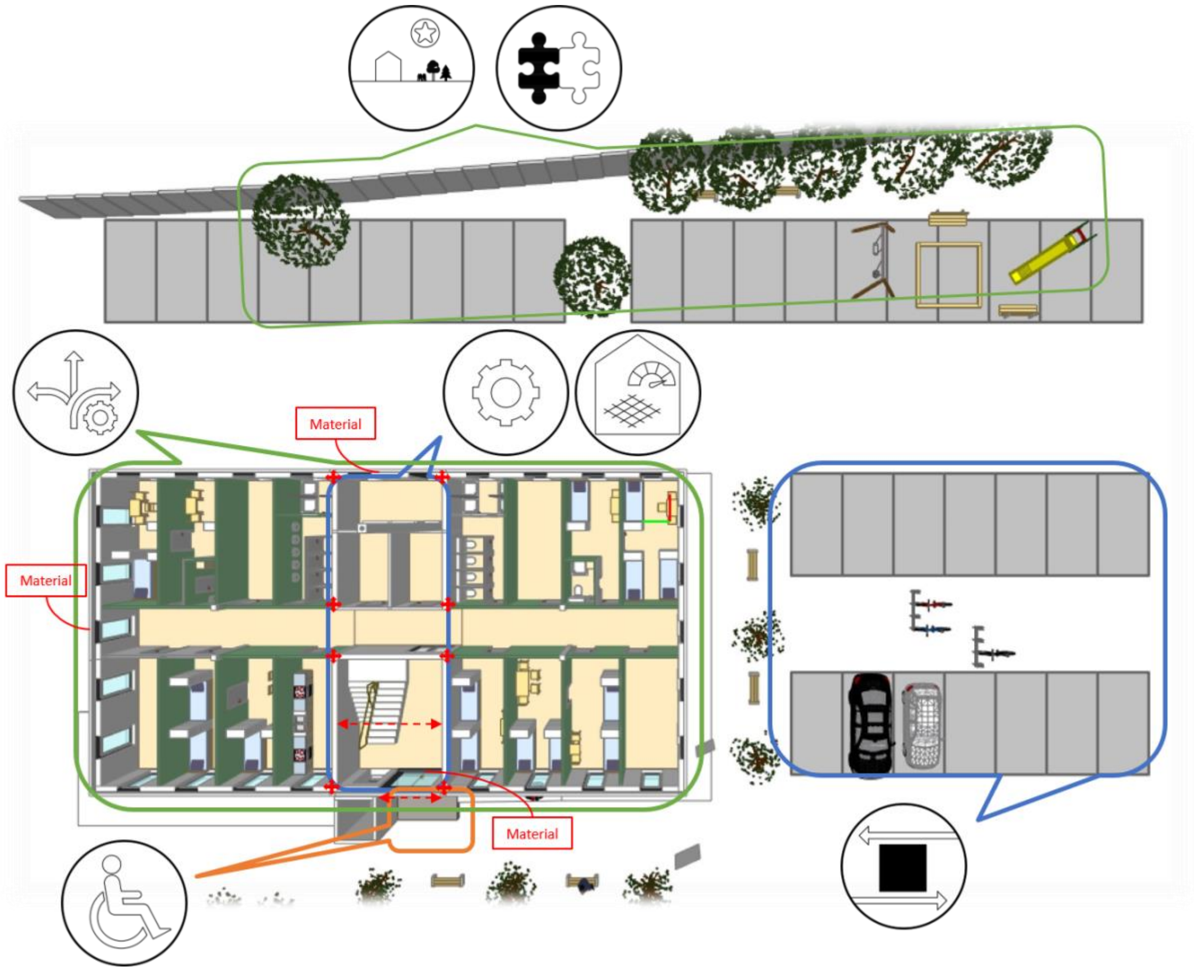


Figure 11: Use case no. 3 - Tausendpfund project, (Copyright Ferdinand Tausendpfund GmbH (Ferdinand Tausendpfund GmbH & Co. KG, Established in 1892)) demonstrating the design ideas using ETs, namely the Use-flexibility tag for the arrangement of the structural elements, Functionality and Spatial efficiency tags for the wrapping and centralization of the core with vertical circulation and services, together with some constraints for material and position of these elements, some other tags include Accessibility for parking spots, the Barrier-free access for the ramp on the entrance door, External space quality and Spaces for social integration for the green space outside the main building

The exterior walls of the building are built floor by floor in three different solid construction methods. The load-bearing material is reinforced concrete on the ground floor, thermal insulation bricks on the first floor, and sand-lime bricks on the second floor. In addition, a composite thermal insulation system is used as external insulation for the outer walls. The three exterior wall constructions each have approximately the same heat transfer coefficient (U-value) of 0.18 to meet the *Effizienzhaus KfW55* standard (Vollmer *et al.*, 2019). The floor slabs, the load-bearing interior walls, and the roof slab are constructed of reinforced concrete. Designing according to this kind of requirement demands careful consideration of the various aspects of the design, which influence the design performance and embedded concepts. Accordingly, documenting which requirements were fulfilled using which design concepts is essential for communicating the design solution to the owner or the different domain experts involved in the project. As demonstrated in Figure 11, using explanations tags and constraints describe the designed concepts and helps the owners and domain experts understand the reasoning that went into the design.

5. CONCLUSION AND FUTURE WORK

The construction industry is a knowledge-intensive sector that draws on a diverse set of skills from a variety of sources (Joe *et al.*, 2013). For many years, the industry has amassed explicit information in the form of building codes, manuals, best practice guides, standards, processes, and so on. Furthermore, individuals with certain expertise and experience possess tacit knowledge. If a strategy to capture such knowledge is not established as people retire, many knowledge-intensive organizations will risk a constant loss of unrecoverable valuable knowledge (Calo, 2008). It's more difficult to formalize, maintain, and exchange this sort of knowledge. The master-apprentice relationship was and still is a common method of passing on tacit knowledge. There is also a broad gap between research and practice, which implies that vital knowledge is sometimes overlooked. This can lead to 'reinventing the wheel' or making the same mistakes over and over again. Architectural firms must adopt a systematic and consistent approach to design process documentation as construction gets more complicated and clients become more demanding. Documenting design knowledge, intentions, and decisions is a fundamental step for communicating with owners and domain experts. Additionally, it facilitates the future evaluation and re-use of completed projects, which can support decisions during the use and facility management of these projects as well as provide guidance when designing new projects. We believe that proper design documentation can lead to better reuse of design knowledge and experience, and optimize design decisions in current projects. From the authors' point of view, the design rationale contained in numerous projects is a precious and insightful source of knowledge that if captured and documented properly could be used and learned from to make better decisions.

BIM models have the potential to serve as procedural realizations of multidisciplinary knowledge, but currently, they store information rather than knowledge. Existing BIM models include raw geometries and semantics but lack any justification or explanation of design decisions. Existing methodology such as storytelling can help facilitate the transfer of design knowledge, however, a tool for documentation in this regard is missing for BIM authoring tools. In this paper, we tackled this problem and introduced novel solutions for it. We started by posing the question of how design decisions can be explained and digitally documented thoroughly based on existing conditions and assumptions. We introduced an innovative solution for the designers to express their motives and argumentation for numerous design decisions. The most remarkable result to emerge from this study is that a framework and meta-model is presented to encapsulate not just the details of design models but also the subjective justifications behind design decisions and choices (more details can be found in sections 3.1 & 3.2). Our study provides the blueprint for a new and holistic way to document the design process.

This paper presented a methodology that comprises multiple concepts to address this gap. First, explanation tags, as well as semantic and spatial constraints were introduced to capture the implemented design concepts and intentions. By applying explanation tags, the rationale and reasoning behind design decisions are captured and envisioned in a comprehensible and graphical way. It should be noted that while the proposed non-exclusiveness aspect of the explanation tag concept brings freedom to create and assign user-defined terms and descriptions, it should be advised to watch out for potential overuse of this feature that can increase the risk of semantic derivations, which in turn hinders the communication and reuse of design. Through the use of constraints, certain design details are laid down as frameworks that keep the integrity of design decisions as the design progresses. Furthermore, we introduced the concept of design episode to divide and store different parts of the overall design that each addresses a certain design challenge or task. By means of design episodes, different chapters of a design are described through storytelling that helps others understand the process and the reasons behind certain decisions. NLP techniques were then employed to query and link design requirements and episodes, which are in a natural text format, to one or multiple building elements, properties, or constraints. Such a link coupled with explanation tags enhances the design documentation with regard to both subjective (qualitative) and objective (quantitative) aspects of design.

The proposed methodology was evaluated for applicability via a prototype that was implemented as a plugin in Autodesk Revit. Additionally, the methodology was applied and discussed in the context of three use cases, which include two real-world projects. Accordingly, the use cases have shown the suitability of the proposed methodology for the current state of practice. For future research, the proposed methodology will be extended to support the search for and reuse of design knowledge across various reference projects and multiple design options. Further evaluations via user studies are intended to enhance the understandability and usability of the developed approach. Moreover, intensive and conclusive design documentation in sample projects, from start to end, is planned as future steps. In addition, our future research will focus on the reuse and utilization of the captured design knowledge for current and future design processes and projects. The captured design rationale will be queried and searched for, and for this purpose, the different BIM query languages will be evaluated for querying and filtering BIM models.

6. ACKNOWLEDGMENTS

We gratefully acknowledge the support of the German Research Foundation (DFG) for funding the project under grant FOR 2363 (*DFG - FOR 2363: Evaluation of building design variants in early phases on the basis of adaptive detailing strategies*). We also thank Ferdinand Tausendpfund GmbH (*Ferdinand Tausendpfund GmbH & Co. KG*, Established in 1892) for providing their office building as a sample project. Likewise, we appreciate the Carl-Viggo Hølmebakk (*Carl-Viggo Hølmebakk AS*, founded in 1990) for their Concrete House design.

7. REFERENCES

Abualdenien, J. and Borrmann, A. (2019), “A meta-model approach for formal specification and consistent management of multi-LOD building models”, *Advanced Engineering Informatics*, Vol. 40, pp. 135–153.

Abualdenien, J. and Borrmann, A. (2020a), “Formal analysis and validation of Levels of Geometry (LOG) in building information models”.

Abualdenien, J. and Borrmann, A. (2020b), “Vagueness visualization in building models across different design stages”, *Advanced Engineering Informatics*, Vol. 45, p. 101107.

Abualdenien, J. and Borrmann, A. (2021), “PBG: A parametric building graph capturing and transferring detailing patterns of building models”.

Abualdenien, J., Schneider-Marin, P., Zahedi, A., Harter, H., Exner, H., Steiner, D., Singh, M.M., Borrmann, A., Lang, W., Petzold, F. and others (2020), “Consistent management and evaluation of building models in the early design stages”, *ITcon*, Vol. 25, pp. 212–232.

Ackoff, R.L. (1989), “From data to wisdom”, *Journal of applied systems analysis*, Vol. 16 No. 1, pp. 3–9.

Ayzenshtadt, V., Espinoza-Stapelfeld, C., Langenhan, C. and Althoff, K.-D. (2018), “Multi-Agent-Based Generation of Explanations for Retrieval Results Within a Case-Based Support Framework for Architectural Design”.

Bettig, B. and Shah, J. (2001), “Derivation of a standard set of geometric constraints for parametric modeling and data exchange”, *Computer-Aided Design*, Vol. 33 No. 1, pp. 17–33.

Bhooshan, S. (2017), “Parametric design thinking: A case-study of practice-embedded architectural research”, *Design studies*, Vol. 52, pp. 115–143.

BIMForum (2019), *Level of Development Specification Guide*, available at: http://bimforum.org/lod/ (accessed 29 October 2019).

Böhme, G., Eliasson, O. and Pallasmaa, J. (2014), *Architectural atmospheres: On the experience and politics of architecture*, Walter de Gruyter.

Borrmann, A., König, M., Koch, C. and Beetz, J. (2018), “Building information modeling: why? What? How?”, in *Building Information Modeling*, Springer, pp. 1–24.

Borrmann, A., König, M., Koch, C. and Beetz, J. (2021), *Building Information Modeling: Technologische Grundlagen und industrielle Praxis*, Springer.

Bracewell, R., Wallace, K., Moss, M. and Knott, D. (2009), "Capturing design rationale", *Computer-Aided Design*, Vol. 41 No. 3, pp. 173–186.

Brown, N.C. and Mueller, C.T. (2019), "Design variable analysis and generation for performance-based parametric modeling in architecture", *International Journal of Architectural Computing*, Vol. 17 No. 1, pp. 36–52.

Calo, T.J. (2008), "Talent management in the era of the aging workforce: The critical role of knowledge transfer", *Public Personnel Management*, Vol. 37 No. 4, pp. 403–416.

Carl-Viggo Hølmebakk AS (founded in 1990), available at: https://www.holmebakk.no/ (accessed 02/22/2021 10:05:40).

Chen, P.-H. (2020), "Essential elements of natural language processing: what the radiologist should know", *Academic radiology*, Vol. 27 No. 1, pp. 6–12.

Ching, F.D.K. and Winkel, S.R. (2018), *Building codes illustrated: A guide to understanding the 2018 international building code*, John Wiley & Sons.

Colic, N. and Rinaldi, F. (2019), "Improving spaCy dependency annotation and PoS tagging web service using independent NER services", *Genomics & informatics*, Vol. 17 No. 2.

Concrete House - Carl-Viggo HAS (Stange, Norway, completion in 2015), available at: https://www.holmebakk.no/project/concrete_house (accessed 22 February 2021.246Z % This file was created with Citavi 6.3.0.0).

Cross, N. (1982), "Designerly ways of knowing", *Design studies*, Vol. 3 No. 4, pp. 221–227.

Demian, P., Ruikar, K., Sahu, T. and Morris, A. (2016), "Three-Dimensional Information Retrieval (3DIR): exploiting 3D geometry and model topology in information retrieval from BIM environments", *International Journal of 3-D Information Modeling (IJ3DIM)*, Vol. 5 No. 1, pp. 67–78.

"DFG - FOR 2363: Evaluation of building design variants in early phases on the basis of adaptive detailing strategies", available at: https://www.dfg.de/en/funded_projects/current_projects_programmes/list/projectdetails/index.jsp?id=271444440&sort=nr_asc&prg=FOR (accessed 6 June 2022).

Domeshek, E. and Kolodner, J.L. (1993), "Using the points of large cases", *Ai Edam*, Vol. 7 No. 2, pp. 87–96.

Domeshek, E.A. and Kolodner, J.L. (1992), "A case-based design aid for architecture", in *Artificial Intelligence in Design'92*, Springer, pp. 497–516.

Eastman, C., Lee, J., Jeong, Y. and Lee, J. (2009), "Automatic rule-based checking of building designs", *Automation in construction*, Vol. 18 No. 8, pp. 1011–1033.

Eisenstadt, V., Langenhan, C. and Althoff, K.-D. (2019), "Supporting architectural design process with flea".

Ferdinand Tausendpfund GmbH & Co. KG (Established in 1892) (accessed 01/27/2021 13:32:02).

Flemming, U. (1994), "Case-based design in the SEED system", *Automation in construction*, Vol. 3 No. 2-3, pp. 123–133.

Fuchs, M., Hartmann, F., Henrich, J., Wagner, C. and Zeumer, M. (2013), *SNAP Systematik für Nachhaltigkeitsanforderungen in Planungswettbewerben-Endbericht: Forschungsprogramm Zukunft Bau / Aktenzeichen: 10.08.17.7-11.38*, Druckerei des Bundesministeriums für Verkehr, Bau und Stadtentwicklung, Bonn, available at: https://www.nachhaltigesbauen.de/fileadmin/publikationen/SNAP_1_Empfehlungen-korr.pdf.

Funkhouser, T., Min, P., Kazhdan, M., Chen, J., Halderman, A., Dobkin, D. and Jacobs, D. (2003), "A search engine for 3D models", *ACM Transactions on Graphics (TOG)*, Vol. 22 No. 1, pp. 83–105.

Gänshirt, C. (2012), *Werkzeuge für Ideen: Einführung ins architektonische Entwerfen*, Walter de Gruyter.

Gao, G., Liu, Y.-S., Wang, M., Gu, M. and Yong, J. (2015), “A query expansion method for retrieving online BIM resources based on Industry Foundation Classes”, *Automation in construction*, Vol. 56, pp. 14–25.

Gero, J.S. (1990), “Design prototypes: a knowledge representation schema for design”, *AI magazine*, Vol. 11 No. 4, p. 26.

Gero, J.S. and Kannengiesser, U. (2014), “The function-behaviour-structure ontology of design”, in *An anthology of theories and models of design*, Springer, pp. 263–283.

Geyer, P. and Singaravel, S. (2018), “Component-based machine learning for performance prediction in building design”, *Applied energy*, Vol. 228, pp. 1439–1453.

Habraken, N.J. (1997), “Forms of understanding: thematic knowledge and the modernist legacy”, *The Education of the Architect, MIT Press, Cambridge, MA*, pp. 267–293.

Harfield, S. (2007), “On design ‘problematization’: Theorising differences in designed outcomes”, *Design studies*, Vol. 28 No. 2, pp. 159–173.

Heylighen, A., Martin, W.M. and Cavallin, H. (2007a), “Building stories revisited: unlocking the knowledge capital of architectural practice.”, *Architectural Engineering and Design Management*, Vol. 3 No. 1, pp. 65–74.

Heylighen, A. and Neuckermans, H. (2001), “A case base of case-based design tools for architecture”, *Computer-Aided Design*, Vol. 33 No. 14, pp. 1111–1122.

Heylighen, A., Neuckermans, H., Casaer, M. and Dewulf, G.P.M. (2007b), “Building memories”, *Building Research & Information*, Vol. 35 No. 1, pp. 90–100.

Heylighen, A., Neuckermans, H. and Morisse, P. (2003), “What you see is what you get”, *IEEE multimedia*, Vol. 10 No. 3, pp. 48–56.

Honnibal, M. and Montani, I. (2017), “spaCy 2: Natural language understanding with Bloom embeddings, convolutional neural networks and incremental parsing”, *Unpublished software application. https://spacy. io*.

Hua, K., Fairings, B. and Smith, I. (1996), “CADRE: case-based geometric design”, *Artificial Intelligence in Engineering*, Vol. 10 No. 2, pp. 171–183.

Hua, K. and Faltings, B. (1993), “Exploring case-based building design—CADRE”, *Artificial Intelligence for Engineering, Design, Analysis and Manufacturing*, Vol. 7 No. ARTICLE, pp. 135–143.

Inanc, B.S. (2000), “Casebook. An Information Retrieval System for Housing Floor Plans”.

Janson, A. and Tigges, F. (2014a), *Fundamental concepts of architecture: The vocabulary of spatial situations*, Walter de Gruyter.

Janson, A. and Tigges, F. (2014b), *Fundamental concepts of architecture: The vocabulary of spatial situations*, Walter de Gruyter.

Joe, C., Yoong, P. and Patel, K. (2013), “Knowledge loss when older experts leave knowledge-intensive organisations”, *Journal of knowledge management*.

Jung, N. and Lee, G. (2019), “Automated classification of building information modeling (BIM) case studies by BIM use based on natural language processing (NLP) and unsupervised learning”, *Advanced Engineering Informatics*, Vol. 41, p. 100917.

Klein, G. (1993), *Naturalistic decision making: Implications for design*.

Klein, G., Orasanu, J., Calderwood, R., Zsambok, C.E. and others (1993), *Decision making in action: Models and methods*, Ablex Norwood, NJ.

Kolltveit, B.J. and Grønhaug, K. (2004), “The importance of the early phase: the case of construction and building projects”, *International Journal of Project Management*, Vol. 22 No. 7, pp. 545–551.

Kuznecova, N.G. and Löschmann, M. (2008), "Deutsch für Architekten: Arbeit am Fachwortschatz", *Das Wort: Germanistisches Jahrbuch GUS*, Vol. 2008, p. 47.

Langenhan, C., Weber, M., Liwicki, M., Petzold, F. and Dengel, A. (2013), "Graph-based retrieval of building information models for supporting the early design stages", *Advanced Engineering Informatics*, Vol. 27 No. 4, pp. 413–426.

Lawson, B. (2018), *The Design Student's Journey: Understanding how Designers Think*, Routledge.

Lee, G., Sacks, R. and Eastman, C.M. (2006), "Specifying parametric building object behavior (BOB) for a building information modeling system", *Automation in construction*, Vol. 15 No. 6, pp. 758–776.

Lee, J.-H., James, P., Garrett, H., Stephen, P. and Lee, R. (2002), "Integrating housing design and case-based reasoning", *School of Architecture and Institute of Complex Engineered Systems (ICES)*.

Liebich, T., Adachi, Y., Forester, J., Hyvarinen, J., Richter, S., Chipman, T., Weise, M. and Wix, J. (2013), "Industry Foundation Classes IFC4 official release", *Online: http://www.buildingsmart-tech.org/ifc/IFC4/final/html*.

Lin, J.-R., Hu, Z.-Z., Zhang, J. and Yu, F. (2016), "A natural-language-based approach to intelligent data retrieval and representation for cloud BIM", *Computer-Aided Civil and Infrastructure Engineering*, Vol. 31 No. 1, pp. 18–33.

LIN, C.-J. and CHIU, M.-L., "Smart Semantic Query of Design Information in a Case Library", in pp. 125–136.

Maher, M.L., Balachandran, M. and Zhang, D.M. (1995), *Case-based reasoning in design*, Psychology Press.

Martin, W.M., Heylighen, A. and Cavallin, H. (2003), "Building² Stories. A hermeneutic approach to studying design practice".

Martin, W.M., Heylighen, A. and Cavallin, H. (2005), "The right story at the right time", *AI & SOCIETY*, Vol. 19 No. 1, pp. 34–47.

Mattern, H. and König, M. (2018), "BIM-based modeling and management of design options at early planning phases", *Advanced Engineering Informatics*, Vol. 38, pp. 316–329.

Meng, Z., Zahedi, A. and Petzold, F. (2020), "Web-Based Communication Platform for Decision Making in Early Design Phases".

Mubarak, K. (2004), "Case based reasoning for design composition in architecture", *Pittsburgh, Carnegie Melon University*.

Neuckermans, H., Heylighen, A. and Morisse, P. (2002), "Visual Keys to Architectural Design".

Odusami, K.T. (2002), "Perceptions of construction professionals concerning important skills of effective project leaders", *Journal of Management in Engineering*, Vol. 18 No. 2, pp. 61–67.

Oxman, R.E. (1994), "Precedents in design: a computational model for the organization of precedent knowledge", *Design studies*, Vol. 15 No. 2, pp. 141–157.

Polanyi, M. (2009), *The tacit dimension*, University of Chicago press.

Richter, K., Heylighen, A. and Donath, D. (2007), "Looking back to the future".

Rittel, H.W.J. and Webber, M.M. (1973), "Dilemmas in a general theory of planning", *Policy sciences*, Vol. 4 No. 2, pp. 155–169.

Rowley, J. (2007), "The wisdom hierarchy: representations of the DIKW hierarchy", *Journal of information science*, Vol. 33 No. 2, pp. 163–180.

Ryle, G. (2009), *The concept of mind*, Routledge.

Salama, D.M. and El-Gohary, N.M. (2016), "Semantic text classification for supporting automated compliance checking in construction", *Journal of Computing in Civil Engineering*, Vol. 30 No. 1, p. 4014106.

Schmidt-Belz, B. and Hovestadt, L. (1996), “Scenario of an integrated design support for architects”, *Design studies*, Vol. 17 No. 4, pp. 489–509.

Schön, D.A. (1987), “Educating the reflective practitioner”.

Schweizerischer Ingenieur- und Architekten-Verein (2004), *SNARC - Systematik zur Beurteilung der Nachhaltigkeit von Architekturprojekten für den Bereich Umwelt (Dokumentation)*, SIA Schweizerischer Ingenieur- u. Architektenverein.

Singh, M.M., Singaravel, S., Klein, R. and Geyer, P. (2020), “Quick energy prediction and comparison of options at the early design stage”, *Advanced Engineering Informatics*, Vol. 46, p. 101185.

Smith, I., Lottaz, C. and Faltings, B. (1995), “Spatial composition using cases: IDIOM”.

Smith, I., Stalker, R. and Lottaz, C. (1996), “Creating design objects from cases for interactive spatial composition”, in *Artificial Intelligence in Design’96*, Springer, pp. 97–116.

Souza, C.B. de (2012), “Contrasting paradigms of design thinking: The building thermal simulation tool user vs. the building designer”, *Automation in construction*, Vol. 22, pp. 112–122.

SpaCy (2021), *Word Vectors and Semantic Similarity*, available at: https://spacy.io/usage/vectors-similarity (accessed 29 January 2021).

Steinmann, F. (1997), “Modellbildung und computergestütztes Modellieren in frühen Phasen des architektonischen Entwurfs”, Bauhaus University, Weimar, Germany, 1997.

Taha, D., Hosni, S., Sueyllam, H. and Streich, B. (2007), “The Role of Cases in Architectural Practice and Education Moneo: An Architectural Assistant System”.

Tang, A., Babar, M.A., Gorton, I. and Han, J. (2006), “A survey of architecture design rationale”, *Journal of systems and software*, Vol. 79 No. 12, pp. 1792–1804.

Uhm, M., Lee, G., Park, Y., Kim, S., Jung, J. and Lee, J. (2015), “Requirements for computational rule checking of requests for proposals (RFPs) for building designs in South Korea”, *Advanced Engineering Informatics*, Vol. 29 No. 3, pp. 602–615.

Vollmer, M., Schneider-Marin, P., Harter, H. and Lang, W. (2019), *FERD. TAUSENDPFUND - Lebenszyklusanalyse und Gebäudemonitoring*, Bayerischer Bauindustrieverband e.V. (BBIV).

Voss, A. (1997), “Case design specialists in FABEL”, *Issues and applications of case-based reasoning in design*, pp. 301–335.

Wiesbaden, S.F. (2013), *HOAI 2013-Textausgabe/HOAI 2013-Text Edition: Honorarordnung für Architekten und Ingenieure vom 10. Juli 2013/Official Scale of Fees for Services by Architects and Engineers dated July 10, 2013*, Springer-Verlag.

Wilbur, W.J. and Sirotkin, K. (1992), “The automatic identification of stop words”, *Journal of information science*, Vol. 18 No. 1, pp. 45–55.

Wu, S., Shen, Q., Deng, Y. and Cheng, J. (2019), “Natural-language-based intelligent retrieval engine for BIM object database”, *Computers in Industry*, Vol. 108, pp. 73–88.

Zahedi, A., Abualdenien, J., Petzold, F. and Borrmann, A., “Minimized Communication Protocol Based on a Multi-LOD Meta-Model for Adaptive Detailing of BIM Models”, in *EG-ICE 2019*.

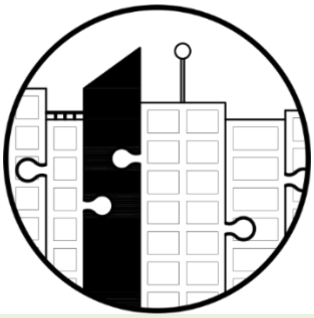
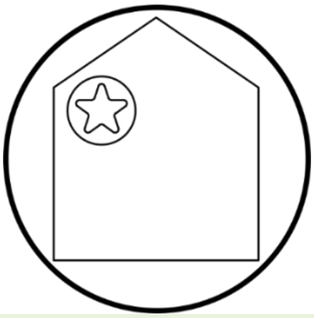
Zahedi, A. and Petzold, F. (2018), “Utilization of simulation tools in early design phases through adaptive detailing strategies”.

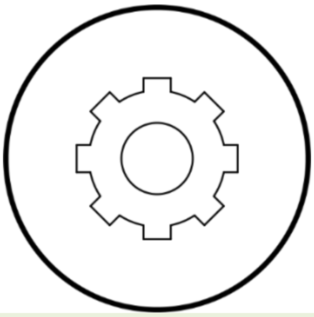
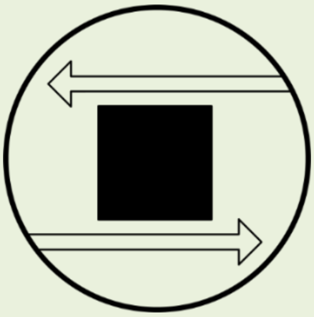
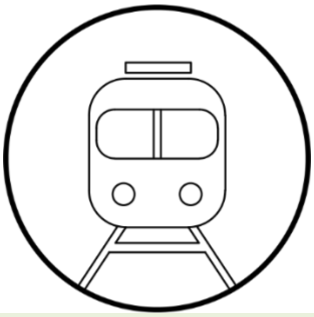
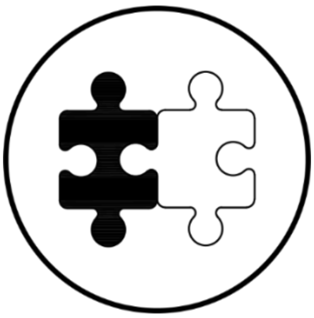
Zahedi, A. and Petzold, F. (2019), “Adaptive Minimized Communication Protocol based on BIM”.

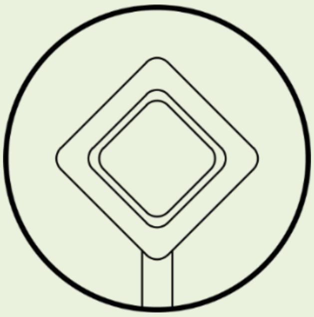
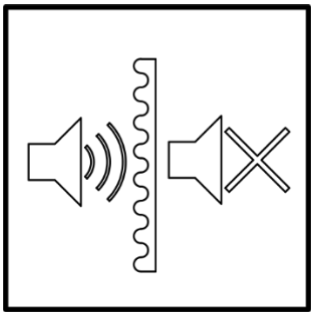
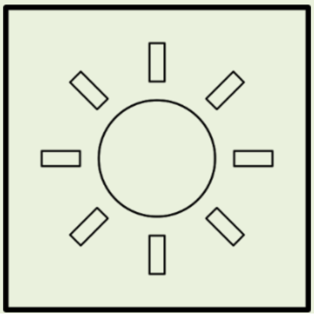
Zeiler, W., Savanovic, P. and Quanjel, E. (2007), “Design decision support for the conceptual phase of the design process”.

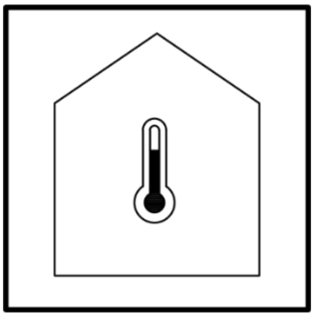
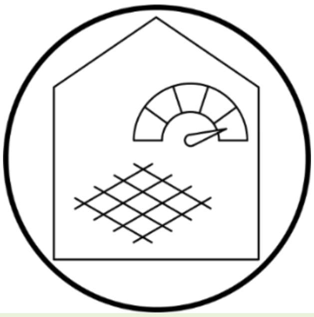
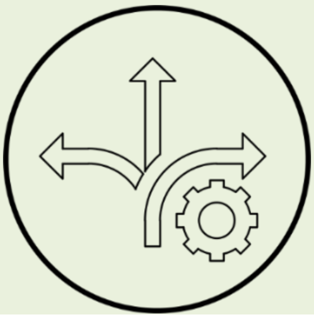
Zhang, C., Zhu, A., Zhou, L., Che, M. and Qiu, T. (2020), “Constraints for Improving Information Integrity in Information Conversion From CAD Building Drawings to BIM Model”, *IEEE Access*, Vol. 8, pp. 81190–81208.

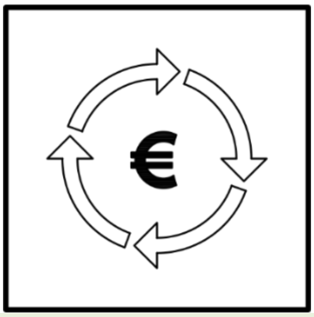
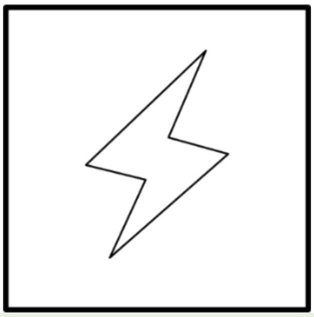
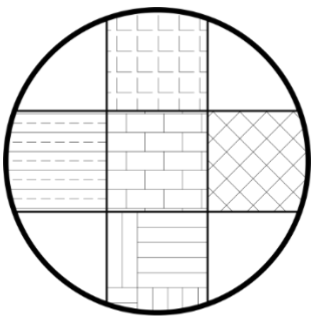
APPENDIX A. EXPLANATION TAGS

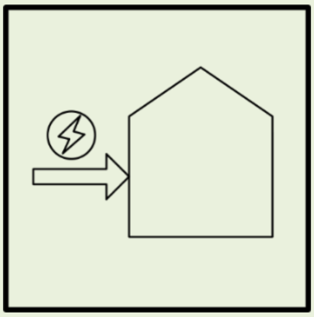
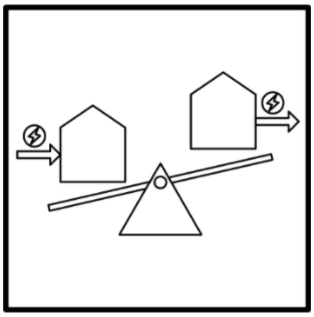
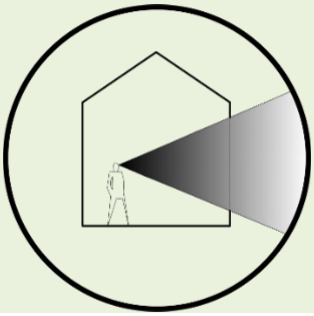
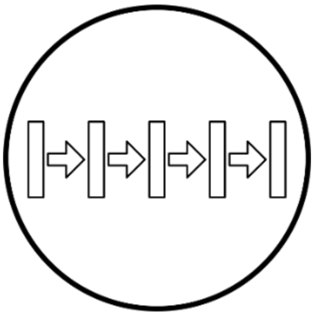
Topic	*Explanation Tag*	*Description*
Design Quality		Design quality may involve many aspects including client requirements to building codes and regulations. In general, it expresses how well the design meets client values and how its impact would be on the environment and the local community. It is also closely connected to urban integration and building as well as external space quality. (Fuchs *et al.*, 2013)
Urban integration		The building will significantly characterize the surrounding buildings and public street spaces. A solitaire is expected as an accent in the urban space, but at the same time, it should fit the neighborhood, blend with the environment, and altogether support the urban image of a place. (Fuchs *et al.*, 2013)
External space quality		Creation of optimal local and user-specific social spaces for urban spaces and ground floor areas, as well as a roof design acting as a "Fifth facade to promote a three-dimensional cityscape." (Fuchs *et al.*, 2013)
Building quality		As a contribution to the building culture, the building ensemble should be of a high degree of design quality and should have a specific Identity, and it should contribute to solving current social problems. (Fuchs *et al.*, 2013)
User and task-specific image		A proper self-presentation and identity formation can be achieved through equilibrium between usability and design. (Fuchs *et al.*, 2013)

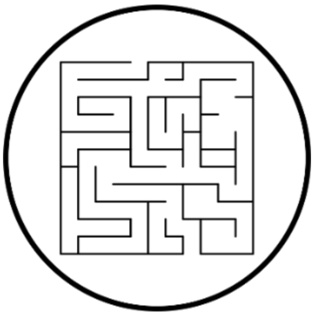
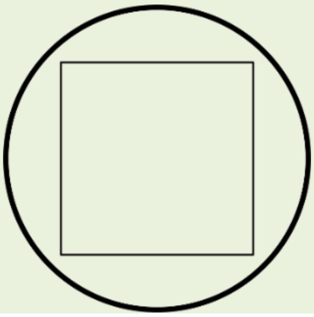
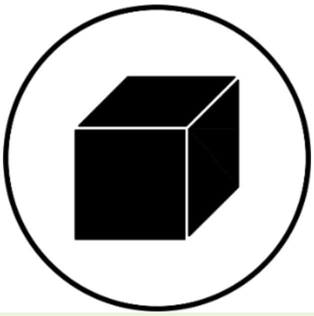
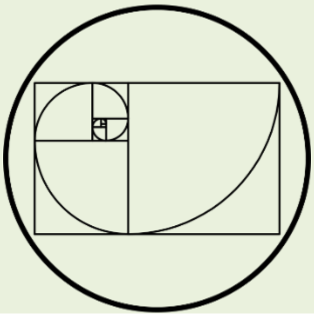
Functionality		Utilitas as one of three foundations and essential components of successful architecture by Vitruvius (the ancient Roman architect) means utility, **functionality,** or commodity and provides an efficient arrangement of space and mechanical systems to meet the functional needs of its occupants. Functionality is also closely connected to accessibility, spatial efficiency, and use flexibility. (Janson and Tigges, 2014b)
Accessibility		Based on the existing or projected road and traffic network, an external and internal development concept is to be developed that ensures good networking with the neighborhood, unmistakable orientation options, good clarity, and secure accessibility. A high degree of cycling comfort should support the development of environmentally-friendly mobility. **Excellence rating:** driveway considered; supply and disposal easily accessible; good access to the underground parking; good positioning of bicycle parking spaces; number of bicycle parking spaces fulfilled (e.g., 10 pcs.); main entrance easy to recognize; short internal ways (Fuchs *et al.*, 2013)
Public access		A high degree of public accessibility promotes the integration and acceptance of the buildings within the neighborhood. (Fuchs *et al.*, 2013)
Barrier-free access		The barrier-free design should ensure unrestricted freedom of movement, increase communication in the building for people with disabilities and enhance the spatial qualities of architecture and open space. **Excellence rating:** barrier-free access to all rooms (elevator on each floor); barrier-free entrance (ramps in entrance area) (Fuchs *et al.*, 2013)
Spaces for social integration		Caring for social contacts supports responsibility, creativity, and building social networks. This is promoted by semi-public areas, communication-promoting development and meeting areas, and a well-coordinated interaction of the private, semi-public, and public areas of buildings and their environment. In addition, the widest possible range of accommodation options should promote communication. (Fuchs *et al.*, 2013)

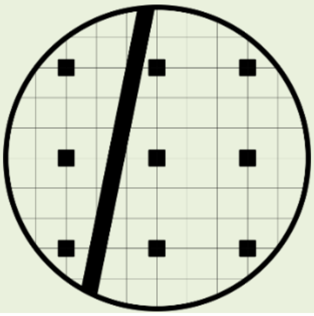
Comfort		A sense of physical contentedness, which comes from many physically measurable conditions, such as light intensity, atmospheric humidity, temperature, air exchange, and noise intensity. Alongside the physical measures, a spatial situation also interferes with comfortableness, including room size, spatial proportions, and gestures.
Health		Health in building design covers a wide spectrum of physical, mental, and social wellbeing of the residents. It is also closely connected to the feeling of safety and security.
Safety & Security		Security contributes to social and economic stability. Users should feel safe in the building itself, as well as in its environment, and be protected as far as possible. Accordingly, the objective hazard potentials (e.g. site-specific natural hazards such as flooding, stumbling blocks, fire, etc.) should be eliminated as far as possible and the subjective sense of security (e.g., clarity, social control/animation, good visibility, etc.) should be strengthened. Fire safety requirements and clear escape routes should be considered. (Fuchs *et al.*, 2013)
Sound insulation		Unwanted noise and acoustic conditions affect well-being and can affect health. By appropriate conceptual and structural measures, pleasant acoustic conditions are to be established. This applies equally to the structural sound insulation against external noise and noise pollution between different rooms. **Excellence rating:** favorable orientation of vulnerable areas; favorable orientation of private open spaces; structural noise protection measures considered; no conflicts of use. (Fuchs *et al.*, 2013)
Daylight		Daylight influences the hormonal balance through the daily routine of the sun and synchronizes our "internal clock." Adequate daylighting should be ensured in workspaces and lounge areas. At the same time, a favorable availability of daylight contributes to a reduction of the artificial lighting requirement and thus of the energy demand. A visual connection to the outside is to be provided for all workplaces and lounges.

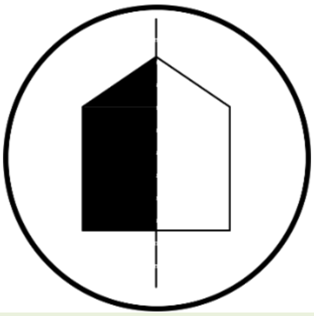
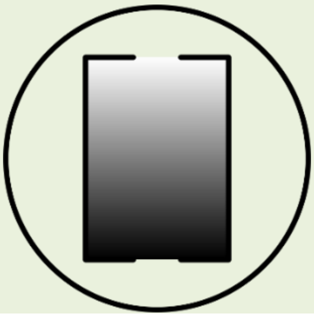
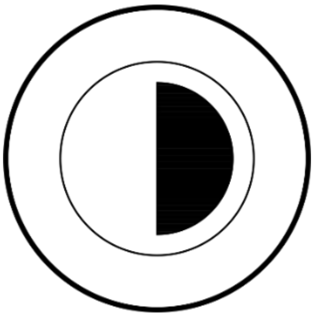
Interior climate		Thermal comfort has a significant influence on the human heat balance and has a direct impact on the energy consumption of buildings. It is to be optimized as far as possible by passive structural measures: e.g. generally by construction methods, coordinated window area ratio and components capable of storing heat; against overheating by sun protection devices, and possibilities for night cooling. **Suggestion**: Sensible passive measures to optimize the indoor climate (construction, storage capacity of building components, orientation). The total glass area of exterior walls should not exceed 50-60% (differentiated by cardinal points and uses); highly effective sun protection; openable windows, possibility for night cooling; rooms with the same temperature should be located together within a building (zoning). (Fuchs *et al.*, 2013)
Economy		Includes all the aspects that affect the cost and budget associated with the building project. It is also closely connected to material and resource efficiency, reuse, and recycling.
Spatial efficiency		Space efficiency cannot be optimized without limitations. However, taking into account the legal constraints (e.g., transit areas), the aim is to achieve the most efficient and economical utilization possible.
Use flexibility		A high degree of convertibility and flexibility is directly related to the sustainability of buildings. As a result, the building structure should be optimally designed to facilitate changes of use. Depending on the planned main use (e.g., office), the positioning of the access cores and toilets should ensure that the building can be divided into different units at a later date. (Fuchs *et al.*, 2013)

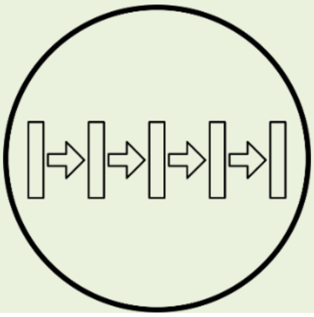
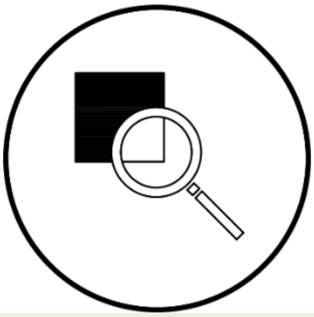
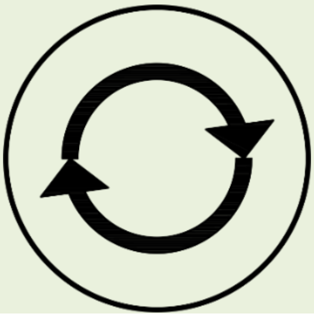
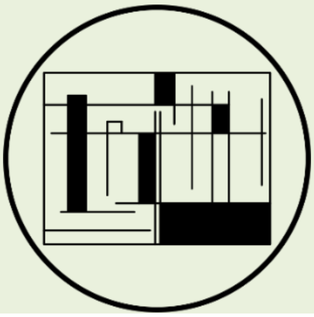
Life-cycle cost		Low investment costs can improve the accessibility of buildings for broad sections of the population, but in the case of long-lived buildings, they must not be at the expense of durability, ease of maintenance, and energy requirements during operation. Accordingly, an optimized ratio of investment-costs-to-utilization-costs (pre-design-relevance, primarily in terms of energy, maintenance, and cleaning) should be aimed for.
Resources		Sustainable and efficient use of resources including time, cost, and human labor are among the most important factors in designing a building. It is also closely connected to budget, life-cycle cost, and energy efficiency.
energy		Energy, in general, is referred to as the capacity to do work which takes several forms such as electricity, heat, light, wind, etc. The sources of energy could be renewable or nonrenewable. The energy aspect is closely connected to energy demand of the building and how to cover that using efficient and sustainable sources.
Surface sealing (Heat island effect)		An economic land utilization and building density allows for sensible use of scarce land resources. In addition, the degree of sealing must be minimized, and suitable compensatory measures must be taken when designing the exterior (extensive meadows and lawns, retention areas and biotopes, trees and hedges, roofs, and green facades). The microclimate should be positively influenced by landscaping or construction measures. Its effect on the "heat island effect," the indoor climate, and human well-being are of great importance.
Material		In addition to the energy demand and the energy demand coverage (criterion 14-15), the selection of building materials and constructions with the lowest possible environmental impact offers a particularly high potential for the reduction of greenhouse gases. In addition, the durability of the building fabric is important for resource requirements. Choice of material and surface finish should ensure long service life. **Excellence rating:** low proportion of sealed areas (32%); Compensatory measures provided (green roof, PV); low solar absorption BRI low (90%); covering area low (93%); building mass below the ground low (83%); high

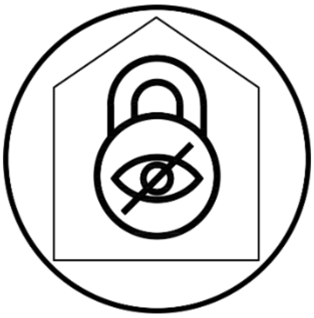
		proportion of renewable resources; façade durable (e.g. wooden shingles). (Fuchs *et al.*, 2013)
Energy demand		Considering the climate protection and economic total cost analysis, it is important to achieve an energy-optimized construction, which ensures a significantly reduced energy demand and thus reduced energy and operating costs. The target values of the applicable EnEV (e.g. 2009) are to be undercut (e.g.) by 50%. Structural and conceptual measures ensure the lowest possible energy consumption for the following energy services: building heating and possibly cooling, hot water preparation, air extraction, lighting. (Fuchs *et al.*, 2013)
Energy demand covering		By examining all locally available renewable energy sources, the obvious use of potentials, and the convincing integration of solar technology into the building envelope, the best possible conditions must be created for using a high proportion of renewable energies to meet the energy demand. **excellent rating:** high PV power demand coverage (170%); high heat yields solar technology (60%); Solar technology formally integrated; used locally available energy potentials; high efficiency of building technology (PEF <0.4); Appropriateness of the technical areas considered average PV power demand coverage (80%); (Fuchs *et al.*, 2013)
View		A double-sided visual trajectory for overcoming spatial division. Towards the outside, view takes part actively in the external surroundings. A view into the interior of a residence breaks open the separation and the protection of the realm.
Sequence		The linear succession of elements, in a way where each figure follows a previous one, with a switch between contrasting situations, which also endows a change in the mental state. E.g., the transition from a dark and confined space to a brighter and larger one gives the experience of expansion in the bodily sphere, the increase in room height stimulates a heightened posture.

Readability		The capability of conveying inherent contents or narrating stories, allowing the beholder to identify and comprehend the spatial structure or constructive principle.
Complexity		Complements and contradicts simplicity. Complexity generates an enjoyable sensation of overwhelming stimulus, which can be achieved via variety and richness of spatial situations—form, color, material, lighting, ambiguities, contrasts, and even contradictions. However, complexity highly depends on the scale and angle of vision. What appears complex when viewed up close may seem simple when viewed as a totality from a distance, and vice versa. A special source of complexity is the diversity of a legible space design; a spatial complex is never perceived from a single viewpoint. Also, complexity leads to indeterminacy or a lack of orientation.
Simplicity		Complements and contradicts complexity and is connected to Gestalt. An intensity of experience in place of a multiplicity of stimuli, where the perception can focus on the details of the simple gestalt.
Gestalt		As a building never appears as a separated collection of its individual forms, the figure of a building and its surroundings are observed as a Gestalt, which represents the principle of "the whole is more than the sum of its parts." Gestalt depends on a stimulus field or suggestive architecture, as our perception is able to render constructive configurations out of fragments. (Janson and Tigges, 2014b)
Composition		In a composition, the parts are assembled into an articulated unity in a way that can achieve equilibrium between the self-sufficiency of the parts and the integrative force of the whole. In a way, composition is a means of avoiding arbitrariness, as it reflects the intention of the structure, as well as demonstrates its meticulous crafting.

Experience		A total impression given by the overall appearance of a room alongside its character, as having a special function, an invitation, a symbolic effect, or an emotional appeal. Perceivers are not only viewing the architecture as beholders but indulging and belonging to the architectural reality. An experience is an individual experiential event that is imbued with special meaning.
Plan Libre		As introduced by Le Corbusier as a free plan arrangement of non-structural partitions determined by functional convenience.
Concept		Concept is the guiding idea behind the design and the spatial creation. It is also the key to fully understanding the completed work, as the result will not be experienced as an object, but as a situation. Concepts also buy into the architectural fantasy and can be an interpretation of the task of the building.
Atmosphere		An element that surrounds the viewer, generated from nearly all the elements of the architecture in totality. Common types of atmosphere include spatial gesture; giving an impression of being spacious or expansive, elevating or uplifting. Orientation, in which a space turns inwards or outwards. Atmospheric qualities include being melancholic, heroic, cozy, festive, and so on. An atmosphere may prompt the viewer to engage in certain behavior such as sitting down, falling silent, or stopping. “The character of a space or place is not merely a visual quality, as is usually assumed. The judgment of environmental character is a complex fusion of countless factors that are immediately and synthetically grasped as an overall atmosphere, feeling, mood, or ambiance.” (Böhme *et al.*, 2014)

Symmetry		Symmetry is a formal quality for the arrangement of spaces. It is a design approach that makes e.g., the opposite sides of a floor plan the same. It is associated with the use of symmetrical shapes and forms. The term symmetrical is also used for a design that has a feel of being balanced.
Personal Style		Personal Style of design or an architectural theme lays claim to an intellectual content having general validity. The architects have at their disposal several themes, which deal with a specific architectural phenomenon and bear their personal style.
Expression		Connected to Atmosphere. The impression given by the architectural forms, **e.g.** the steepness of a staircase, the closed appearance of a façade, or the protective gesture of a roof. Such expressions can be comprehended through direct perception of the architectural elements, without revealing the concealed subject matter, yet may remain at times quite diffuse and difficult to examine. Expression and Atmosphere cannot clearly be differentiated. (Böhme *et al.*, 2014)
Closure		Restricted views, accessibility, and movement. Views can be restricted via canalization through intermediate spaces. Closure can vary between absolute impermeability and complete openness. Closure can also be connected to the sky view, as the less outer view is permitted, the more closed a building or a square would be.
Contrast		Contrast in general is defined as the state of being remarkably different from something else in comparison or close association. Contrast could be practiced by various sizes and various textures in a composition or in different combinations, e.g., the use of light vs dark.

Transition		Transition is defined as the process or a period of changing from one state or condition to another. In architecture, transition is defined as the connecting in-between spaces. It is the passage from one state, stage, subject, or place to another and architectural spaces are incomplete without transitional spaces.
Transparency		Transparency means "permeability to light." We refer to elements and materials as transparent when we are able to see through them. We speak of translucency when light passing through a material produces only a schematic impression of the objects behind it. In general, transparency refers to the covering up, obscuring, or displacement of spatial delimitations. (Janson and Tigges, 2014b)
Continuity / Space-Body Continuum		Mass and space complement each other and merge together in a continuous fashion. Masses are turned outwards, while spaces conversely are directed inwards. However, masses contain spaces and also form spaces outwardly, creating a space-body continuum. Space-body continuum is related to the dual role of the surface (columns or projections), the reversal of figure-ground relationship, and the transition between scales.
Immensity		Monumental effects of size that are intended to overwhelm the viewer. However, it cannot be arrived at simply by continually increasing the volume of a building. Because the impression of architectural size cannot simply be equated with sheer dimensions, such effects are generated through special architectural measures, which are designed to avoid falling into banal gigantism. (Janson and Tigges, 2014b)
Aesthetics		***Venustas*** as one of three foundations and essential components of successful architecture by *Vitruvius* (the ancient Roman architect), regarded as beauty or delight, is responsible for aesthetic quality, imparted style, proportion and visual beauty.

Privacy		“In a highly general sense, the interior stands for privacy, possession and in-gathering, the exterior for the public sphere, availability and dispersal.” (Janson and Tigges, 2014b) Privacy could be defined and interpreted through other terms and concepts such as accessibility and exclusivity, protection, cell, facade, inside and outside, residence, screening, territory, view into/out of, closure to extensive openness, the requirements of separation.