Interaction with analysis and simulation methods via minimized computer-readable BIM-based communication protocol

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The early stages of building design are characterized by a continuous endeavor for the development of variants and their evaluation and consistent detailing. The concept of adaptive detailing aims to enable the architect to evaluate and compare design variants which are partially incomplete and vague (Zahedi and Petzold 2018b). This paper discusses a minimized communication protocol based on BIM, which enables computer-readable interactions between the architect and different domain-experts (representing various analysis and simulation procedures) (Zahedi and Petzold 2018a). This comprises the selection of simulation procedures as well as any necessary consolidation of the information content according to the requirements of the simulations. Any additions required on the part of the simulation procedures are visually prepared globally or space-and component-oriented respectively, in order to perform detailing of a building model in a targeted way. Moreover, this paper proposes various supportive methods for visual representation and exploration of analysis results.

Keywords: *Building Information Modeling (BIM), Early Stages of Design, Adaptive Detailing, Minimized Communication Protocol*

INTRODUCTION:

Early stages of the building design are particularly important since decisions made in these phases will significantly determine the performance of the final building. More importantly, as the design process proceeds any changes to the decisions made in the early phases will impose extra costs and time loss on the project budget and schedule. As we move on from conceptual and early design phases into more detailed design, the ability to impact design will decrease dramatically while the cost of change will increase intensely (MacLeamy 2004). These early phases are also characterized by a continuous effort to create design variants, evaluate them and continue with their detailing. For the evaluation of design variants, the designer uses different criteria such as the owners' requirements, building performance, and cost. Objectifiable assessments like simulations and analytical procedures in early design phases are currently only used in part or with great approximations in model details and uncertainty involved with the results. The reasons for this are the insufficient process integration of supporting software solutions and the required model quality for accurate results that are lacking in early design phases. Some overall approximate simulation tools exist for these early phases of design, but their results contain mostly high uncertainties and additionally, in some cases, these analytical methods may have taken some simplifications and assumptions into account that the architect is unaware of them.

The Architecture, Engineering, and Construction (AEC) industry is among the largest industries in the world while having a unique nature that puts a high demand on communication and collaborative work. Communication and collaboration play a significant role in the effort to improve building design activity. Building information modelling (BIM) in its nature pursues the gaol to integrate and manage all the semantical and geometrical information related to construction projects. This feature in BIM enables new possibilities for exchange of information in digital format between different actors, such as architects and consultants, in a construction project. Thus, improving the access to computer-aided analysis from the early stages of design (Borrmann et al. 2018). The downside to this approach is that the planning effort and the sheer load of design decisions are shifted to the early stages of design too. Thus, leaving the designers to decide on so many details early on while they are not yet sure about them. This could also be seen as if the system forces these details on the architect with little knowledge about their consequences (Zeiler et al. 2007).

In other words, the main problem with these critical early stages of design is that in most cases concerning design decisions, the architect hasn't made his mind yet. It means that for every design decision, there exist so many choices and options, which the architect is either unaware of them or of their effect and consequences on the final design's cost and future performance. In addition to that, the architect is not and cannot be an expert in various fields of analysis and simulations that are needed to evaluate different design variants. This necessitates the need for asking different domain-experts and consultants to assist and support the architect in his design decisions. The research project EarlyBIM (funded by the German Research Foundation (Deutsche Forschungsgemeintschaft) under the grant number DFG-FOR2363) is devoted to the development of methods for adaptively detailing the partially incomplete and vague building design models in order to assess and compare different design options.

STATE OF THE ART

Facing numerous decisions during the important early stages of building design, the architect must make compromises since many design objectives are conflicting due to their dependency on each other. The process of Decision-making in building design has been investigated by many researchers using the Multiple Criteria Decision Making (MCDM) approach. Two methods are used to solve MCDM problems, namely Multiple Objective Decision Making (MODM) and Multiple Attribute Decision Making (MADM). Simply stated, in MODM the designer ends up knowing what ideal design variant he aims for and in MADM he finds out between a limited number of alternatives which one he likes the most. For example, Jalaei et al. proposed a solution to integrate a Decision Support System (DSS) using MCDM with BIM to support the designer in choosing the optimum sustainable building components (Jalaei et al. 2015).

Despite the insufficient information available during early design stages, BIM models appear precise and explicit. This may lead to false assumptions and assessment. Abualdenien & Borrmann introduced a Meta-Model for incorporating the inherent fuzziness involved in geometric and semantic information of individual building elements during these early stages. They also introduced a new concept called Building Development Level (BDL), which describes the maturity of the overall building model (Abualdenien and Borrmann 2019). This paper uses the BDL concept in order to specify the information requirements with respect to building elements and their maturity to carry out a model analysis. These adaptive information exchange requirements are called aLODx in our minimized communication protocol and are defined based on the above mentioned multi-LOD meta-model. An aLODx acts as an adaptive lookup table or translation table to which both the architect and domain-expert will refer when communicating based on our minimized communication protocol (Zahedi et al. 2019).

Considering the importance of collaboration and internal communication between different actors involved in building design, BIM Collaboration Format (BCF) was first introduced in 2010 as an open standard to enable BIM-based workflow and communication between different parties and different software vendors. Using the BCF, the project participants create topics (such as issues, proposals, and change requests) that contain various attributes like type, description, and comments. Each topic will be linked with a model element as well as a viewpoint and possible screenshots. This eliminates the need to exchange entire bulky digital BIM-models between software applications. (buildingSMART 2017) However, BCF XML is dominantly used for gasping human-readable data regarding issue management. Even though BCF v2.1 is capable of encompassing so-called BIM-Snippets to encapsulate schematized arbitrary data, yet the BCF is still mostly been used to address human-readable issue management in AEC and examples of implementing BIM-Snippets are not yet commonly introduced. Example of a BIM-snippet could be a partial IFC file.

MINIMIZED COMMUNICATION PROTOCOL

To implement the adaptive detailing of partially incomplete and vague design models in early design stages, this paper uses an adaptive minimized machine-readable BIM-based protocol for communication between the architect and various specialist planners (domain experts). The proposed minimized communication protocol used for adaptive detailing is composed of two parts. The first part is responsible for the management and sorting of communication interactions between different actors. It implies a standard ticketing system (also known as issue tracking system). Each request for analysis generates a ticket. In simple words, each ticket will contain information on what type of analysis was requested, by whom it was requested, who's responsible for it, what is its current status and so on. Some common features in this ticketing system are as follows:

- Register a request for analysis (or a ticket)
- Assign an owner, or person responsible, to the ticket
- Assign additional interested parties to the ticket
- Track changes to the ticket
- Inform interested parties of these changes
- Launch activity based on ticket status or priority
- Report on the status of one or more ticket(s) - an overview
- Finish with, or close, the ticket once the activity is concluded.

The second part of this communication protocol contains the feedback provided by various consultants and domain experts. Furthermore, the issues and messages traded between different actors using this protocol are designed to be machine-readable through predefined schemas. Human-readable communication could be comments (free-form text) and snapshots (with free-form annotations), while machine-readable communication is based on predefined and agreed upon schemas, which enables the computer to read, filter and analyse the trafficked messages afterwards. Using this protocol, all communications, variant evaluations, and decision-making will be documented and traceable afterwards for further use cases. Considering the fragmented nature of AEC industry with many small and medium-size companies whose collaborations are mostly limited to the duration of one project, we believe that through machine-readable communica-

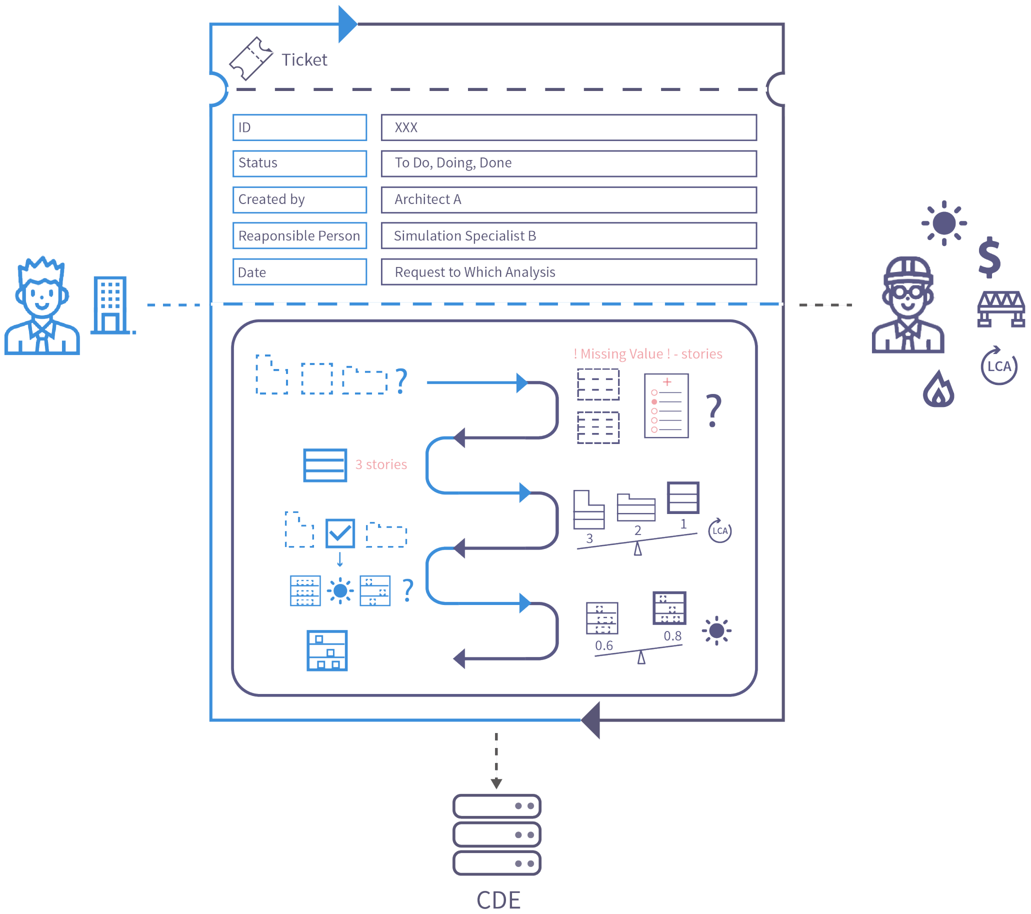

Figure 1
Outline of the Minimized Communication Protocol

tions, we'll be able to learn from the partnerships and interactions of various building projects and that might help to improve this less advanced industry.

Based on the explicit exchange requirements needed for each analysis (examples in our research group are the energy & structural analysis) a specific schema is defined for each analysis (using the requirements planning via Multi-LOD Meta Model (Abualdenien and Borrmann 2019)) that contains all the essential components (spatial and semantical building components) with their corresponding crucial attributes and LOD (Level of Development) within the BIM data model. This part uses an adaptive signature function called 'Feedback' to exchange the missing information along with suggested values for them as options. This signature function based on its use case will receive different arguments. The feedback function in its general form is as follows:

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feedback (actionType, optionGroupID,
 ↪ GUID, aLODx, ComponentID,
 ↪ PropertyID, value)
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Each of the arguments that the feedback function receives along with two demonstrative examples for energy analysis and structural analysis has been explained in the following publications (Zahedi et al. 2019; Zahedi and Petzold 2019).

IDENTIFICATION AND INTERACTIVE EXPLORATION

During the early design phases, the building models are characterized mostly by containing incomplete or vague information. In order to obtain meaningful simulation results, a partial detailing of the information content according to the requirements of the simulations might be necessary. The aim is that the domain-experts (responsible for various analysis and simulation methods) can request additional information in design models if they are not sufficiently detailed. The information deficits identified in this way must be indicated to the designer (architect) in an appropriate manner so that he can make the necessary detailing decisions.

Moreover, communication and visualization go hand in hand in order to ensure good collaboration between different actors to evaluate the developed design variants. Visualization is an essential part of communication and exploration. Throughout this adaptive detailing, visualization consists of two major domains. One being the modifications and reporting of missing details in BIM models, and the other one is the representation of different analysis and simulation results along with the illustration of assessments and evaluations of respected design variants. The first category mainly consists of illustration and manipulation techniques concerning BIM models content on both spatial and semantical levels. The steps and tasks for visualization design in this domain could be categorized as:

- Missing details report
- Modifications report for the suggested options
- Interactive search with suitable filter techniques
- overview maps and 3D annotation techniques
- manipulation of building components
- dialogue and chat history related to each analysis call

Considering the visualization as an essential part of communication and exploration, in order to ensure good collaboration between different actors, various visualization techniques are suggested in order to properly show the outcome of the model checking to the architect indicating the shortcomings of his design model. For visual identification and exploration of missing information or modified model elements, methods such as overview maps, colour coding and 3D annotations, 2D/3D navigation techniques, walk-through, exploded views, semantic zooms are proposed. Some of these methods are shown in Figure 2. Currently, in user studies, evaluations are carried out using mock-ups that will lead to a better understanding of the architects' (as the possible users of this system) needs and preferences.

CONCEPTS FOR THE REPRESENTATION OF RESULTS

In order to assist and support the architect in his design decisions, different domain-experts and consultants are asked to provide him with analysis and simulations regarding the future performance of his possible design variants. Using analysis results as objective criteria for the assessment of design variants necessitates adequate representation and visualization of these results. The architect (not being an expert in every respected field of analysis) desires an easy-to-understand visualization of all these results. When designing visualizations, many different aspects need to be considered. The quality of the visualization could be assessed via its effectiveness,

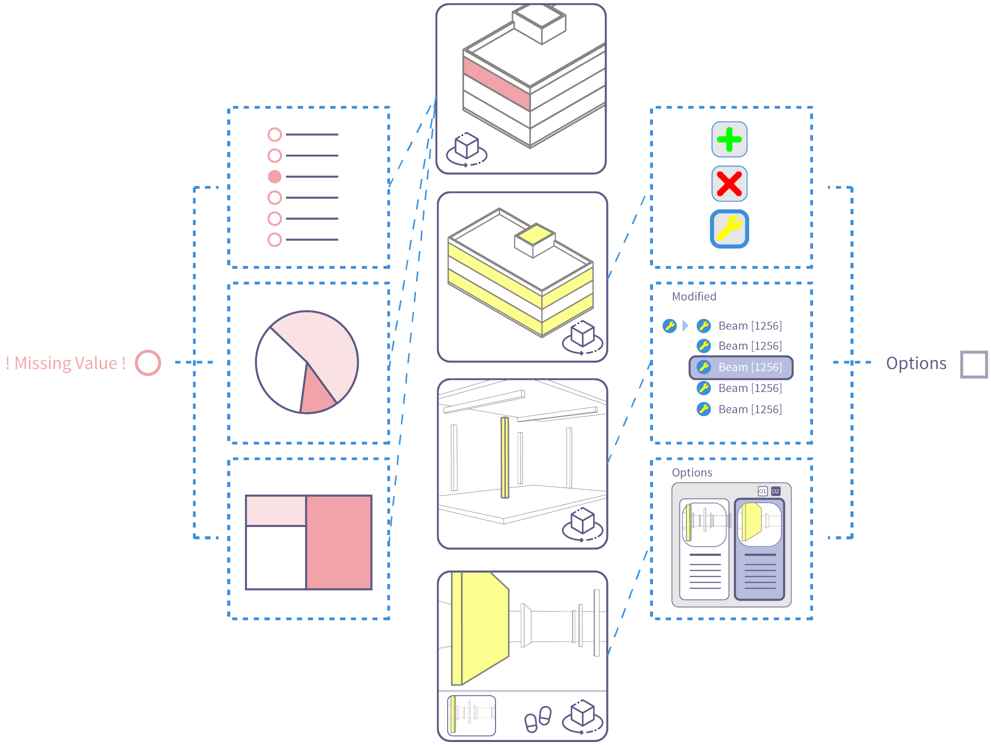


Figure 2
Different Interaction Methods to deal with the Feedback report

expressivity and appropriateness (Mackinlay 1986; Schumann and Müller 2013). The visualization problem is essentially characterized by questions of what is visualized, why and under what conditions. The answers to these questions represent the object, goal and context of the visualization, respectively. The object of the visualization is determined by the underlying data and the goal by the task that the user wants to solve. Characteristics of the user such as his cognitive abilities, experiences and preferences are also influencing in defining the visualization problem. Context represents the background of the application such as established techniques and tools, conventions and metaphors.

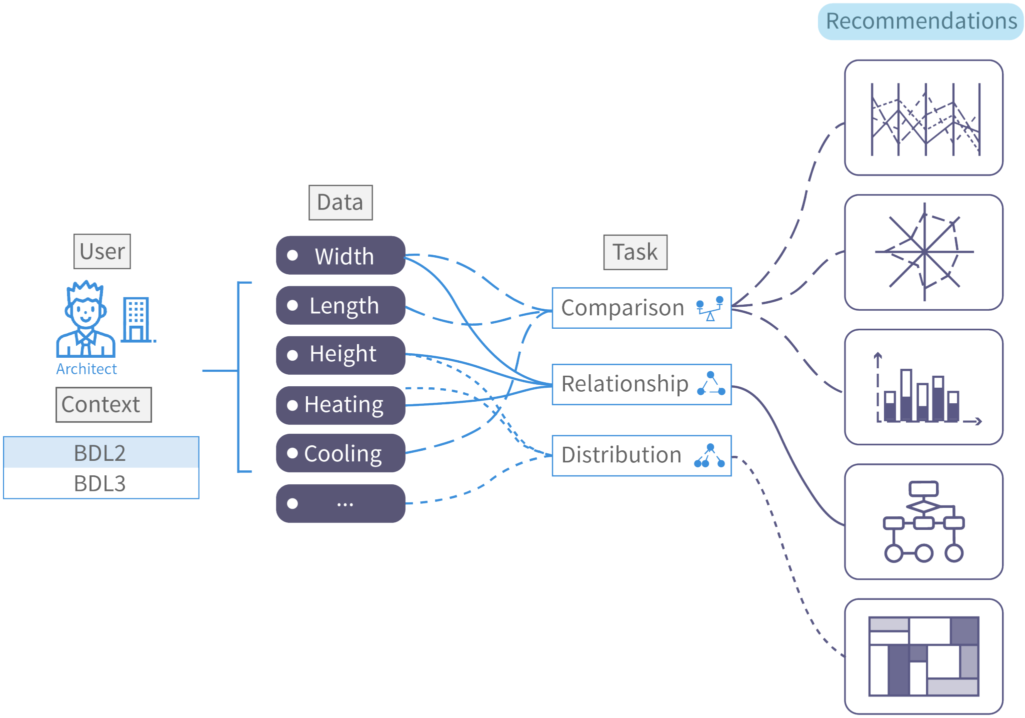
In the first step, the object of the visualization is investigated, which is determined by the underlying data of the simulation results. The examples in our research group are the energy and structural analysis. Following with the user whom in our case is the architect. The architect's ultimate goal is to evaluate and compare design variants using analysis results. The context in our case is the building design which is represented by the Building Development Level (BDL). BDL describes the maturity of the overall building model and its refinements in five levels. In the scope of early design stages, we consider BDL 2 and sometimes BDL 3 suitable for these stages. More details about the BDL concept could be found in (Abualdenien and Borrmann 2019).

In general terms, one of the essential possibilities for user support in visualization is the assistance in visualization design. Assistance methods and procedures can differ based on their targeted aspect of visualization design. In particular, considering the procedure, a distinction can be made between constructive (bottom-up) methods and template-based (top-down) methods (Lange et al. 2006). Most constructive methods are based on a rule-based approach. A prototypical example is being implemented for the 'Visualization Support For Assessment And Comparison Of Building Design Variants' based on constructive (bottom-up) approach. Figure 3 shows the conceptual framework of this prototype while Figure 4 and 5 show the screenshots of the InProgress implementations.

EASY-TO-UNDERSTAND EVALUATION OF DESIGN VARIANTS

The design and realization of a building start in the first place with requirements planning. This includes the exact determination of the client(owner)'s needs and demands. His demands and wishes are noted in both qualitative and quantitative forms in the so-called user requirements program. Starting with the design process, the architect creates multiple design variants overviewing different solutions. The client's requirements will later be used to evaluate and compare these design variants. Favourable and selected design variants are detailed further. As mentioned before the key to improve decision-making during the important early design stages is to involve and corporate with domain-experts regarding different design decisions. As part of a master thesis done by

Figure 3
Support in the selection of visualizations



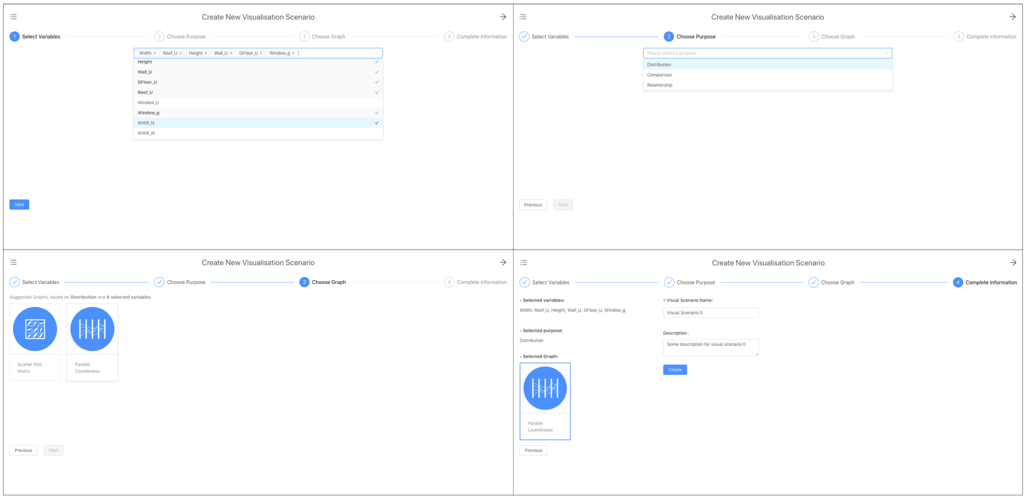


Figure 4
Storyboard screenshots of creating a new visualization scenario

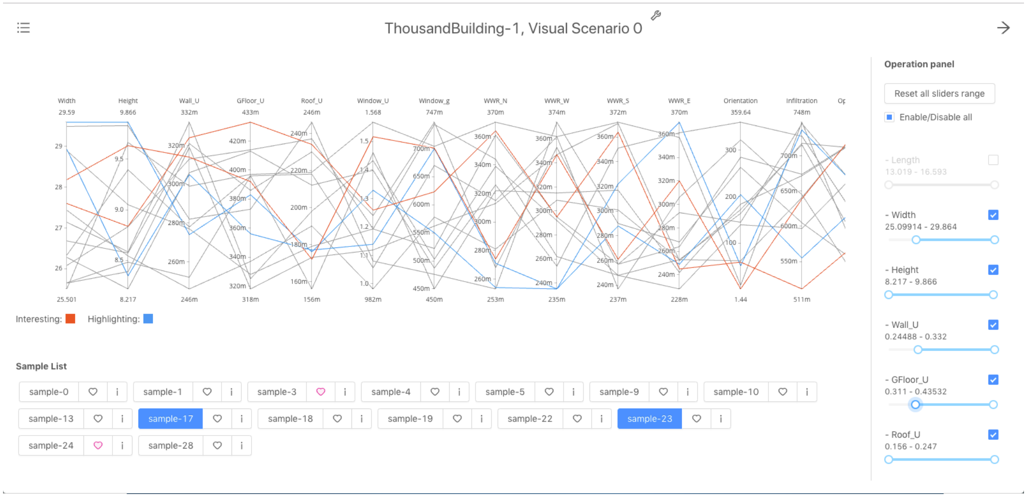
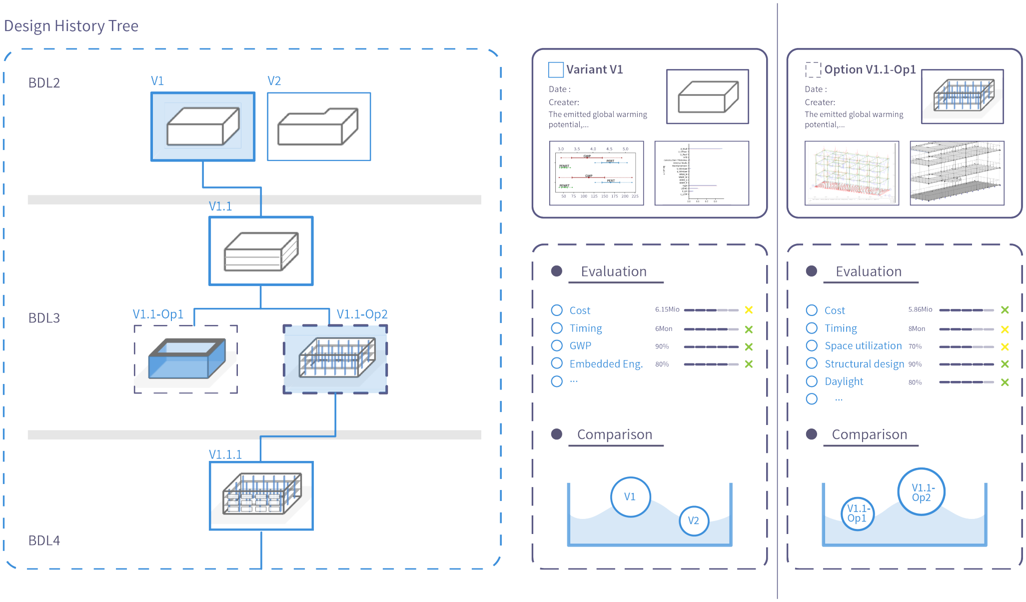


Figure 5
Screenshot of a visualization scenario in our prototype

Figure 6
Design History Tree with Variant-Cards and Variant Comparison using KPIs



Carolin Wolff (Carolin Wolff 2018), a total of 15 experts in the AEC industry, including university professors and industry professionals were interviewed in order to find a framework to facilitate collaboration between the architect and the domain-experts during the early design stages.

Among the users' wishes, stated by interviewees, was to include the history of design in the form of a tree or graph including all variants (created by the architect) and options (suggested by the domain-expert to fulfil information deficits in design model) together with so called variant-cards (Carolin Wolff 2018). The function of a variant-card is to recap and review all the essential info related to each design variant into a card. Each variant-card include a thumbnail of the 3D design model and a short description to recap the variant's properties. The important information associated with each variant plus the results of various analysis and simulations are included in the variant-card. This summarized information is linked with more elaborate and comprehensive explanations, which can be called upon if requested. Using these variant-cards the architect can summarize and sort out his design variants.

The design history tree contains all design variants and options throughout the design process and across different BDLs. It is worth mentioning that this paper distinguishes between design variants and options. Options are partial design models suggested by domain-expert to fulfil the information deficits required for analysis compatibility, whereas design variants are directly created by the architect. The architect as the design team leader can choose from design options to fulfil his needs or reject them. Furthermore, decision points where the architect has made his choice regarding design decisions are visualized on this design history tree. Related evaluations and comparisons on these decision points are likewise visualized. Throughout the design process and while making design decisions, the architect uses various criteria to evaluate and compare his design variants and to make different choices. These criteria may include client's requirements such as cost, time or other functional requests, restrictions and regulations demanded by construction authorities, performance and sustainability of the future building and so on. Each of these factors (criteria) could be seen as a Key Performance Indicator (KPI) for the future building. The KPIs may also include any other subjective indicators that the architect may have in mind. Utilizing the Key Performance Indicators (KPIs) allows the architect to assess and compare different design variants. By means of weighting the KPIs, the architect can set priorities for variant evaluations. Figure 6 suggests a conceptual framework that shows the history of design in the form of a tree. This design history tree also contains the decision points where the architect evaluates and compares his design choices based on adaptable KPIs.

CONCLUSION

Variant evaluation and comparison play a significant role in supporting the decision-making process of the architect during the early stages of building design. This paper discussed the use of a minimized computer-readable communication protocol based on BIM to interact with domain-experts (representing various analysis and simulations). Furthermore, the article explained different methods for visual representation, identification and exploration of feedback reports based on the earlier mentioned protocol. Additionally, a prototypical implementation to support the selection of visualization methods for the representation of simulation results was described. Finally, a framework was designed to enable easy-to-understand evaluation and comparison of design variants.

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