Utilization of Simulation Tools in Early Design Phases through Adaptive Detailing Strategies

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Abstract. Decisions taken at early stages of building design have a significant effect on the planning steps for the entire lifetime of the project as well as the performance of the building throughout its lifecycle (MacLeamy 2004). Building Information Modelling (BIM) could bring forward and enhance the planning and decision-making processes by enabling the direct reuse of data held by the model for diverse analysis and simulation tasks (Borrmann et al. 2015). The architect today besides a couple of simplified simulation tools almost exclusively uses his know-how for evaluating and comparing design variants in the early stages of design. This paper focuses on finding new ways to facilitate the use of analytical and simulation tools during the important early phases of conceptual building design, where the models are partially incomplete. The necessary enrichment and proper detailing of the design model could be achieved by means of dialogue-based interaction concepts with analytical and simulation tools through adaptive detailing strategies. This concept is explained using an example scenario for design process. A generic description of the aimed dialog-based interface to various simulation tools will also be discussed in this paper using an example scenario.

Keywords. BIM; Early Design Stages; Adaptive Detailing; Communication Protocols; Design Variants.

1. Introduction
In recent years, significant planning problems have repeatedly arisen in the construction and operation of multifunctional buildings (e.g. train stations and airports with shopping facilities, concert and hotel complexes, etc.) in the inner city area. These led to higher costs, delays and low social acceptance (Assaf and Al-Hejji 2006). It has been shown that there is a lack of holistic and flexible models and novel methods for the use of digital building models to control complexity and make decisions transparent (Borrmann et al. 2015).

Building Information Modelling (BIM) could be defined as continuous and seamless use of digital building models throughout the entire life cycle (including design, planning, construction, operation and conversion) of the building. Current trends show that BIM will have an important role in the construction industry and will result in a significant modernization of the working procedures. One
The major advantage of BIM lies in the direct reuse of data held by the model for diverse analysis and simulation tasks, as e.g. the structural analysis or the energy performance simulation. This means that BIM could bring forward the planning and decision-making processes (Borrmann et al. 2015). However nowadays, the use of analytical and simulation tools typically requires a mostly completed and detailed design model. Since such analysis and calculations, are mostly dependent on the data from detailed model design, these analytical procedures occur typically at later stages of design, where most of the important design-decisions have already come to pass.

The early conceptual architectural design phases are characterised by a constant interaction for the creation of variants, their assessment and consistent detailing (Buxton 2010). As we move on from conceptual and preliminary design phases into detailed design and construction documentation, the ability to impact cost and functional capabilities of design objects (buildings in this case) decreases dramatically while the cost of design changes increases exponentially (MacLeamy 2004; Borrmann et al. 2015). The architect nowadays almost exclusively uses his know-how for evaluating and comparing design variants. Some overall approximate simulation tools do exist for early stages of design but they are mostly uncoupled with the BIM authoring tools and incapable to handle vague and incomplete input information. Then again, the architect as the designer is indeed no expert in various fields of analysis and simulations needed for evaluating a design alternative. Therefore, understandable evaluation of performance, costs, economics and constructability of different design variants are mainly lacking in these early stages. In addition to that, a variant management system along with the recorded history of the decision-making process and detailing the design model is still lacking in these important stages of design. Main reasons are that building information models are not able to represent the vagueness involved with unelaborated designs and that current simulation methods are mostly not capable to handle vague and incomplete input information.

To address this insufficiency, the research unit DFG-FOR 2363 (“Evaluation of building design variants in early phases on the basis of adaptive detailing strategies”) is dedicated to development of methods that allow the evaluation and assessment of alternative building design variants, which may also be partially incomplete and vague. This research project is in progress and is still fairly in the beginning of its work and this paper publishes the first results concerning one of its part projects namely “TP 3: Visual exploration for assessing design variants”. The focus of this part project in the above mentioned research group is twofold, one to establish a generic dialog-based interface to various simulation tools, and the other to develop methods for visual exploration and easy to understand evaluations of design variants based on simulation results. As the contents of this paper will be describing the preliminary results of our research, it will discuss the concept of detailing-on-demand with a possible scenario of building design in its early stages, following on with the generic description of the aimed dialog-based interface to various simulation tools.
2. Related work

This research group will benefit from the current state of the art in science and the numerous publications published in the field of computer support for building design, among those, the results of the DFG’s priority program 1103 (Rüppel 2007) deserve special mentioning. Within the framework of SPP 1103, network-based methods for improving the cooperation of specialist engineers in the planning process were developed and tested. However, methods of semi-automated, adaptive detailing were not discussed.

Several researchers investigated the possibility of integrating simulation and analytical tools in early phases of building design in order to support the architect in decision-making process. Østergård et al. (Østergård et al. 2016) in a recent review investigates the improvements in applying building performance simulations (focused more on namely the energy simulations) in early design faces. The review categorizes the challenges in these early stages as “handling input uncertainties and variations of design parameters, large design space, rapid change of the design, lack of information and increasing model resolution”, while classifying various research-fields to address them as “proactive simulations, statistical methods, design optimization, CAD-BPS interoperability, holistic design and knowledge based inputs” (Østergård et al. 2016). To better support the decision-making of architects Gadelhak et al. (Gadelhak et al. 2017) presented guidelines and a prototype for visualization tools used in multi-objective design optimizations.

Kim et al. investigated the projection of design variants and the design history as well as the respective navigation, all together to support designing, distorting, and prototypical implementation (Kim et al. 2011). On this basis, approaches for the variant mapping in BIM systems and the integration of energy simulation methods into the design environment for the purpose of decision support were considered. However, it seems that consistent LODs (Levels of Development) including examination as well as situation-related integration of simulation methods containing a feedback detailing were not considered. In addition, it seems that the uniform representation of design variants in a building model besides the consistent combination of variants were not addressed.

Avoiding the problem of multiple separate models with a high amount of redundant information, Mattern and König (Mattern, König) proposed a concept for managing different design variants without creating redundancy. Their approach tries to put different design option within one consistent BIM model using an IFC-based methodology. In this method, three variant classes (structural, functional and product) are proposed to manage the variety of design options. And ultimately suggesting a graph data model to present options in a logical structure (Mattern and König 2017).

Since one major focus of this paper is about developing a proper computer supported communication between the architect (using CAD tools) and the analytical systems and procedures in general, it is essential to review the communication protocols for collaboration environments based on BIM. The most famous collaboration format is the BCF (BIM Collaboration Format) from
BuildingSMART that supports workflow communication in BIM processes. BCF is defined as an XML based schema to exchange mainly written commentary issues relating to a certain IFC file. In addition to that, via the BCF-API software applications can exchange BCF issues in BIM workflows through a RESTful web interface. Each problem or issue in design could be explained using a topic inside a BCF file. bcfXML is a ZIP container holding one folder for each topic. Inside each folder or topic is an XML file called markup.bcf and another one called viewpoint.bcfv and also a picture called snapshot.png (multiple snapshots are also possible since v2.0). The markup file contains metadata about the topic stored as textual information, such as title, date, author, various comments with their dates, and so on (bcfXML v2.1 by buildingSMART 2017). The viewpoint file stores the position of the camera and the related building component attached this issue. The main problem with BCF (especially in version 1) is that it is mainly comment-based and human-usable oriented. The whole purpose behind creating BCF issues are for them to be read and act upon by a human since all the comments are basically only human readable and not machine readable. However, since version 2, a new concept is introduced into BCF in the form of attachments called BIM Snippets, which is claimed to support sending schematized data using for example predefined Model View Definitions (MVD).

3. Adaptive detailing strategies and the concept of Detailing-on-Demand

The creation and evaluation of design variants is an important aspect in the early planning phases, in order to design a building that is as comprehensive and efficient as possible. The central approach of the project is the conceptual design of a multidisciplinary, model-supported design planning with the inclusion of subject-specific simulation and analysis methods. Especially in early design phases, design alternatives should be evaluated in real time. The core of the methodologically new approach is the desired ability of the overall system to deal with different degrees of detail. If the level of development required to carry out a simulation is not available, it should be possible to supplement them interactively and semi-automatically. This concept is referred to as “adaptive detailing” or “detailing on demand” in the context of the project to indicate that detailing is only carried out when an analysis is not possible or the results do not correspond to the desired accuracy. For this purpose, methods for the formal description of requirements for input data on different levels of detail are to be developed. The goal is to define generic interfaces based on these methods, which allow the integration of arbitrary detail-sensitive simulations. The provision of these novel models and methods should enable an efficient assessment of design alternatives with regard to different quality criteria already in the early phases of the building design. This makes it possible to compare different design alternatives on the basis of formal criteria and objectifies the decision in favour of a design alternative. The following scenario explains the concept of detailing on demand.

3.1. SCENARIO

To begin with there are some definitions to be clarified, as shown in Figure 1.
Variant: A variant object (design object, design model) describes an object that is saved in a specific status and time.

Option: An option represents an alternative suggestion from the simulation specialist to the architect in order to detail the design model in a way that the simulations could be run for it. Options exist parallel with the design variant with partially detailed parameters/values and can be kept permanently or temporarily.

The following description explains the progression of design according to Figure 2 and Figure 3. In this figure the horizontal axis shows the course of time while the vertical axis indicates the increase in level of detail of design variants. At the beginning of a project, the architect creates different variants (V1, V2, V3) for a specific site. Without further inquiries or analysis, he decides on one of the variants he had created. To make sure he chose the correct dimensions and structure grid, he requests a simulation (Sim S) for structural analysis. A ticket will be created and thereupon the simulation starts and supplies a result back. This outcome indicates an error because too few information are given. The architect cancels this simulation and the ticket will be closed.

He creates a new variant (V4) and adds more details to the model. Once more, he asks for the model to get checked again by Sim S and opens a new ticket. The analysis (Sim S) starts and again the simulation tools sends back a result with indicated errors. For example, the architect receives the information that all dimensions together with the chosen structure grid are insufficient.
However the architect is unsure about what dimensions and order (layout) would be the best solution and therefore demands for possible suggestions. Following his request, the simulation tools (Sim S in this case) generates three different possible options and suggests them to the architect. Upon the request of the architect to support him in his decision-making all given options will be analyzed and evaluated. Thereupon the architect comes to a decision and chooses one of the options which shows the best results among the others and accepts it. The system will automatically generate a new Variant (V5) by adding the details from the chosen option to V4.
Working further on this Variant the architect decides to ask for another simulation (Sim E). For example, he desires results for a daylight analysis and further on he wants the analytical tools (Sim E in this case) to evaluate and compare two different options for window-to-wall-ratio. Further on, he calls for the structural analysis (Sim S) as before to check the impact of the two window options on the building structure. All Options from both simulation processes (Sim S & Sim E) become combined and analysed. Upon reviewing the cross comparison and evaluation results, when the architect acknowledges and accepts the best combined option, then the system will automatically generate a new variant (V6) based on the previous one by using the combined details from the chosen option.
4. Dialog-based interface to simulation tools

In order to achieve simulation-based assessment for the meaningful evaluation of a design, certain data with a definite depth of information and reliability are required for the calculations and simulations. Based on a digital building model, essential information can be determined and used for the simulation. The requirements depend on the chosen analysis method, the necessary detailing and the desired result quality (level of accuracy). If the available depth of information is not sufficient for a particular simulation, the simulation model can request or suggest further details. The responses from the simulations must be prepared and visualised in a transparent and comprehensible way.

Figure 4 shows the conceptual framework of this dialog-based communication protocol using an example scenario. We start with an example in which at some point during the design process the architect requests for a simulation tool (e.g. Embedded Energy Analysis) and by doing so a ticket will be issued and a light message mainly in the form a link, which clarifies the scope of the requested analysis and the desired level of accuracy for it will be sent to the simulation tools.

On the side of the simulation tools the specialist will receive this ticket and following the link (to a database for digital models) he will access (read-only) the model and checks it for its quality and details required for the entreated simulation with the desired level of accuracy. The outcome of the model checking is sent back and properly visualised to the architect indicating the shortcomings of his model. This so called report will consist of the following:

- Which building components have missing details?
- What component types are each of them?
- Where are they located within the model?
- What LOD is needed for them to satisfy the desired analysis?
- What attributes are missing within those building components?

In this simplified example, the outer-walls’ material is missing. Then again, the architect not being sure of his choice, asks for suggestions among with proper evaluation for the suggested options. The specialist creates four possible options for outer-walls material and then evaluates and compares them, subsequently sending back the results to the architect. The architect upon receiving the report, will choose himself for the better option according to the evaluation results, and the system will automatically add the details (outer-walls material) to his model.

The important points to consider in this concept for dialog-based communication protocol are the following:

- It is a light messaging protocol with mainly links and no actual BIM files to transfer.
- The transmitted communication messages are not text-based (such as comments) and are not aimed only for humans to contemplate them (like BCF), but rather are to be recorded and be readable by computers afterwards. Therefore, each corresponding action and transmitted details for the model with their data types and etc. are to be investigated and determined through case studies and scenarios for various simulation and analysis types.
Through the course of dialog-based communication the architect as the designer will have the right to modify and edit the digital models on the BIM-database and thus to create new design variants. But the simulation specialist can only access the digital models on the BIM-database and then, according to the architect’s needs, create new options and provide them to the architect. Ultimately the architect can choose from these options and the system will automatically add the details to previous design variants and creates a new variant, or he can just discard all of them (the suggested options) and
chose to refine and detail his model by himself and subsequently creating a new variant.

The history of the actions that led to the selection of design variants, in other words the design history, most probably in the form of a version management graph, will be taken into account that can be analysed, filtered and adequately represented.

5. Conclusion and future work

This paper explained the first conceptions and frameworks of a generic dialogue-based communication protocol, which makes the adaptive detailing and enrichment of digital models, possible in early stages of building design. Further investigations are necessary for identification of the essential variables and their required level of detail in order for the simulation methods to function. Subsequently the information deficits identified by the simulation specialist after checking the model, should be displayed to the designer in a suitable way so that he can make the necessary detailing decisions. Ultimately in order to incorporate simulations for the evaluation of variants in the design process, the results have to be adequately presented.

Acknowledgment

The described research is funded by the DFG (Deutsche Forschungsgemeinschaft) as research unit (Forschergruppe) with the funding ID of FOR 2363.

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