Chapter 1

Introduction

1.1 Background and motivation

Building information modelling (BIM)—the semantically explicit modelling of information related to construction projects—is primarily targeted towards the interoperability of computers. During the advancements of BIM, information was removed from its previous close connection with the visual representation in order to achieve the defined semantics. But visual representations must be generated reproducibly and reliably if they are to fulfil their communicational goals. Furthermore, the growing amount of information contained in building information models requires new methods of visual representation, beyond traditional visualization methods.

In parallel to the development of BIM, new media have opened up new perspectives for visual representations. In addition, the efficient and repeated creation of multiple visual representations from the same information is made possible only by the separation of information and visual representation. Engineers and architects as the domain experts should be actively involved in the creation of visualizations, but this is not currently possible, due to technical obstacles.

The role of visual representation in BIM has not yet been sufficiently covered in the field of construction informatics. Consequently, there is a gap between information models and visual representations, related to both knowledge and tool support. This is what this research addresses.

1.1.1 The blind spot of building information modelling

In recent years, BIM has advanced from an academic topic and a visionary concept to an ecosystem of working methods, sophisticated technologies, standards, and tools which is implemented in all major computer-aided design (CAD) software packages, in national building regulations, in local and global best practice suggestions, and increasingly also finds its way into the daily work routines of architectural and engineering offices. The original idea of BIM aims at the explicit modelling of all relevant information regarding architecture, buildings, and the construction process. It further promotes the modelling of this information in a unique and standardized way. In doing so, it opens up new possibilities for computer-aided analysis, design, and production methods, and also for the exchange of architecture and building-specific information in digital form.

However, efforts to facilitate information exchange and to establish interoperability aim primarily at increased interoperability between machines: computers, their hardware, and software applications. The human user is only targeted indirectly, by claiming facilitated communication and cooperation between the persons involved in the construction process through the indirection of digital machinery. BIM research consequently aims at the enhancement of the models, their further standardization and internationalization, the integration of additional information into the models according to new needs—such as energy efficient design and construction—the technical aspects of information access in distributed environments, and the utilization of the information models by analytical tools and methods.

The development of BIM is based on the idea of structuring the information in a semantically explicit, strictly defined way according to an abstract model. This is contrary to the traditional way of maintaining and sharing information using drawings, diagrams, tables, and text documents. Unlike digital information models, these artefacts contained information in an implicit way, requiring human perception and reception to decode the information before it could be used.

The development of BIM was driven by the increasing use of digital tools. It was thus indispensable from an information technology point of view to dissolve this strong implicit containment of information in visual representations. Algorithms need defined input and produce defined output; they are not capable of easily extracting implicit information or of interpreting ambiguous input. It was a natural consequence inherent in the process of information modelling that, by factoring information out of its close containment in visual representations, building information and its visual representation became decoupled. It can even be argued that this process of decoupling was intentional. On account of this development, persistent and shareable visualizations were untied from the information they contained.

As a consequence, the information models which are exchanged between participants during the planning and construction process do not contain the information in a form directly accessible to human perception. Early approaches to the use of digital methods in architecture and construction simply digitized the 2D drawings. In this stage, tools changed and artefacts shifted from physical to virtual, but the visual representation was still contained directly in the documents, which had not yet reached the current abstraction level of building information models.

Nowadays, visual representations have drifted further away from the information they represent. They are no longer contained in the documents that are exchanged, but are instead generated on the fly, when they are needed. This ad hoc generation of visualizations is carried out in the software applications and tools used to solve specific tasks—e.g. in a CAD tool as it generates the model, or in a simulation tool working on energy performance analysis. This drift is problematic for several reasons.

1.1.2 Essentials for communication and exploration

In order to create a visual representation, a separate mediation step is needed. This conversion of the information into a visual representation is currently encapsulated in software applications. Generation of the visualization may yield different results depending on the specific implementation in the application. This may even vary between applications designed for the same specialized task.

One of the functions of visual representation is communication. However, communication needs a common reference. A simple model of communication involves a sender, a receiver, a message, and a medium (e.g. Shannon 1998). The sender encodes information as a message transmitted through a medium, which is then decoded by the receiver. Communication through visual representations can therefore only succeed if both the sending and the receiving end share the same visual representation. The process will fail if encoding and decoding are not symmetric operations, when the message is changed between encoding and decoding, or when the visual representations are produced in unpredictable ways.

Instead, it must be possible to reliably reproduce the same representation for both communication partners. Sharing a common model of the visual representation plays a similar role for communication as a common model of the building for interoperability in general. The effective exchange of visual representations can only work with shared and standardized metamodels. Currently, in the construction domain, open standards regarding visual representations do not exist beyond the traditional paper-based processes.

It is obvious that visual representations are important for making the abstract information in the models accessible to human perception. Larkin & Simon (1987) have analysed the background of the saying that "a picture is worth a thousand words" by comparing sentential and diagrammatic external representations of problems, both with an inherent spatial aspect and without. They uncover why the search and recognition processes of the human brain can operate very efficiently on diagrammatic problem representations.

But beyond that, there is a need for sophisticated visual representations, on account of the growing amount and increasingly complex structure of information. Since the specification of the first BIM standards, the amount of information captured explicitly in information models has grown continuously. Additional semantics are added, such as information relevant for energy efficient building. More details about the building are gathered through simulations and calculations with computational support. Thus, besides the abstractness, the sheer amount of building information begins to elude human perception.

From the time before BIM, there is an extensive repository of traditional visualization methods specific to 3D design topics in general and building-relevant information in particular. Software applications that generate visual representations from building information models do build upon these visualizations and recreate them. However, as models are developing towards aggregated interlinked clusters of multiple single models, such traditional visualization methods begin to fail. While these methods are optimal for representing individual aspects of the building—such as those captured in a single part of the model—they are not capable of reflecting the complex information in an aggregated model interwoven on different levels.

The lack of scalability of traditional visualization methods is one of the forces driving the field of visual analytics (Keim et al. 2010). Visual analytics aims at using visual means to analyse large amounts data based on the fact that the human perception system and the human brain are capable of performing highly complex analytical tasks that are not easily solved by algorithmic methods. Apart from that, only the human brain is currently capable of creating knowledge by assigning meaning to information and contextualizing it in a net of previously created knowledge, thus gaining insight, instead of merely processing information. BIM opens up a wide range of tasks to be solved by visual analysis, but due to the lack of general approaches to visualization, the field of construction does not benefit from these methods.

Andrienko et al. (2007) propose establishing a subfield of visual analytics dedicated to problems with spatiotemporal aspects, where space refers to geographic space. The specific problems identified for geovisual analytics are very similar to those which can be found in architecture and construction: the complex nature of the problem domain, multiple actors, and tacit criteria and knowledge.

1.1.3 The potential of BIM-based visualizations

In parallel with the explicit modelling of information, new forms of visual representations came into existence. Such visual representations are based on the interactivity of the digital screen, as opposed to the static nature of printed text, 2D visualizations, and physical 3D models. Hypertext has revolutionized the possibilities of text, leaving behind the limits of one-dimensionality, allowing the establishment of an interlinked net of text. Similar possibilities were introduced for 2D visualizations by information visualization and related disciplines. Finally, interactivity has also made virtual 3D models possible; these are, in fact, perspective projections in 2D that unlock the third dimension through interactive means.

Information modelling is not a necessary condition, but a parallel development perfectly matching the possibilities of digital media. It facilitates the generation of multiple visual representations from the same model, while enforcing consistency across the representations. An example from the construction domain is the consistency between floor plans and cross sections. Formerly, it was a difficult task for draughtspersons to maintain and ensure this consistency; today, they do not necessarily need to deal with this issue. They still need to give thought to where to place the sections, although this issue too can be supported by algorithms that check for the completeness of the presentation, given a certain set of section planes; such algorithms may even suggest optimal section lines.

The creation of external visual representations is a proven way to actively engage with a problem. For example, to draw an as-is floor plan of a building by hand prior to reconstruction work creates a deep understanding of the anatomy and state of the building, which is needed as a base for any planning work, engineering or architectural, on the reconstructed building. Despite seeming like tedious, useless, and duplicate work, this activity constitutes an essential part of problem solving and decision making. A streamlined data flow across the building life cycle and across domains simplifies the creation of external representations. While this allows for more efficient work flows, it also involves the risk of eliminating an essential technique of problem solving.

Digital media provide alternative ways to engage with the information in order to gain understanding: multiple views of the material through different interactively explorable representations improve access to information over traditional plans and documents. However, browsing through a predefined set of views of the information requires less involvement and thus does not stimulate understanding in the same way as the direct production of visualizations. Involving domain specialists in the generation of digital visual representations could restore the intense engagement with the information, while still benefiting from the new possibilities of digital media and explicit information modelling.

Architects and engineers are not only specialists for specific tasks and problem solutions in their fields, but they have also very special knowledge of the information needed for these tasks and about the visual representations that are suitable for working with the information. Lohse et al. (1994) suggest that domain experts process visualizations differently from nonspecialists (and even from those with an artistic background), in that they more easily extract information from these visualizations when they have an "appropriate graph schema" available. Presumably, this not only promotes the "processing" of, but also the creation of, visualizations and the development of new visualization techniques by domain experts, compared to visualization specialists without a construction background. Consequently, architects and engineers have historically created a rich repository of visual representations, signs and symbols, and visual encoding methods tailored to their domain.

Presentation and communication of planning decisions and of the building before it is realized have always been, and remain, important parts of the work of architects and engineers. Visual representations are an essential communication medium in these areas, because textual descriptions are of limited efficiency for the expression of spatial issues.

Yet visualizations as external representations are also an essential way to engage with the material and to envision the future building during the design and planning stages. Research into the psychology of creative problem solving in design characterizes the process as a continued manipulation of a mental model of the solution, which is represented in a variety of different views, with the goal of bringing these views to a conflict-free state (Balakrishnan et al. 2007). Thus, the decoupling of information and visual representation is also an obstacle to creative design and construction and to exploration-based problem solving.

Because computer science knowledge is necessary to program custom visualization components, architects and engineers, as domain expert users, are excluded from the process of creating visual representations. The arrangement, definition, and design of the visualization process is now inaccessible to them. Reinstating the participation of architects and engineers in the visualization process could also increase the acceptance of BIM and encourage the use of BIM as a method.

1.2 Research question and scope of the work

The drifting apart of information and visual representation has created a gap in both theoretical knowledge and practical technique. It is a theoretical gap in the academic field of construction informatics and a practical gap regarding the tool support for professions involved in design and planning of buildings. This work is based on the hypothesis that it is possible to bridge this gap by making it a topic of similar importance as the information models as such, by analysing the relation between information models, and by creating the tools to work on this interface.

By developing methods to specify and describe visualizations as explicit and formalized as the current information models, and by incorporating these methods in building information modelling tools with accessible interfaces, the creative professions in architecture and engineering could reinstate their expertise in the field of visual representation and re-employ their skills and knowledge in that area.

MacEachren (2004) values knowledge of visual representations as an important issue: "Understanding how maps work and why maps work (or do not work) as representations in their own right and as prompts to further representations, and what it means for a map to work, are critical issues as we embark on a visual information age". His claim refers to the visualization of geoinformation, but can easily be generalized and transferred to architecture and construction.

The result of this work could unfold its potential being used for the purposeful presentation and imparting of planning and analysis results, as well as for the explorative engagement with model data. By facilitating the development of custom task-specific reusable visualization components, a twofold benefit could be achieved: on the one hand, visualization techniques can be used for many models, and on the other hand, model data can be examined using many visualizations from a repository of custom components.

There are some leading questions that extend beyond the scope of this thesis. First of all, the approach is solely concerned with the generation of visual representations from building information models. Other multimedia types, especially audio and audiovisual representations, are ignored, although some results may be transferable to that area. Second, the editing of building information models is beyond the scope of the thesis. However, since building information models are often created or updated by visual means (as opposed to algorithmic or automatic creation or update), the methods described here can potentially also be applied in that context. Third, there is a continuum between interactive visualizations and more general user interfaces, and although user interface (UI) issues are not in the scope of this work, some methods extent into the UI area.

Further, this thesis does not focus on special sophisticated task-specific visualization methods. The specific visualization methods used as examples also contain visualizations with new or experimental approaches to certain contexts. However, these visualizations still only play the role of examples. They are not compared to other visualizations for the same context, they are not evaluated for their usability, and there is no claim about their quality or suitability for the context in question.

1.3 Method and structure of the work

This thesis seeks to examine the process of generating visualizations from building information models. One purpose is to provide the foundation for a suggested field of construction-specific visualization engineering. The second main aim of this research is to propose a way of reinvolving domain experts from the architecture and construction fields into the visualization process.

1.3.1 A model of the visualization process

The model of the visualization process developed in this thesis is based on the reference model of the visualization pipeline.

The visualization pipeline is a commonly accepted reference model for the process of visualization, which splits the process into a three-step transformation from raw data (the information model) to the final visual representation (the image). The inverse process can be used as a model for decoding the visual representation. A large part of the visualization process should be reversible without information loss. This is especially true for the central mapping step, which is in the focus of this work.

Each stage of the pipeline has been investigated: the data side, the visualization side, and the mapping that connects the two. By reviewing the current state of data modelling in the construction domain, the visualization process is embedded in the context of the field. The main focus is on the mapping between the two sides, because this transformation step will essentially be made accessible to domain experts.

Each stage of the visualization process is first described informally, in order to then develop a formal model. The visualization process is examined in terms of its anatomy and in terms of its economics, and hence with a qualitative as well as a quantitative view. Further, for each stage, a simple view is complemented with combination methods to cover complex situations.

1.3.2 The quantitative view

In order to understand the correlation between building information models and visualization, a qualitative view of structural aspects of the visualization process needs to be complemented with a quantitative approach. With a measure of the amount of information in the information model side on one hand, and a measure of the presentable information on the visualization side on the other hand, these two quantities can be compared and contrasted. The comparison of the complexities on the information model side and on the visualization side could yield conclusions for the mapping, and the space of visualization mappings could be narrowed down.

Beyond this, a quantitative view would also allow for a reliable and detailed performance analysis of visual applications. Otherwise, performance measurements can only be related to indicator values, such as the file size or the number of objects. A well-founded quantitative model of the mapping process could also facilitate the visual exploration of building information. By tracing how much of the information has already been included in visual representations, and how much is still pending in the process, visual exploration can be guided towards full coverage and the user can be guarded from overlooking information. Also, promising visual representations can be selected on the basis of their coverage of information.

Quantification of the building information as previously described depends on the type of building and on the characteristics of the planning process. Hence, this will vary by building type and local conventions and regulations. Similarly, the quantitative aspects on the visualization side will vary with technical preconditions, the available device specifications, the recipients' cognitive abilities, and the environmental presentation situation.

1.3.3 Proof of concept implementation and sample cases

Implementation of the model as a software framework verified the feasibility of the approach. The proof-of-concept prototype was implemented as a local application. For a web-based client–server version, the implications and possibilities of a software architecture are only analyzed theoretically, without a second prototypical implementation.

The use-case data for the evaluation of the prototype covers a broad range of potential building models. Beyond a synthetic test case, they comprise different types of small- and large-scale realistic construction projects.

Visualization configurations were obtained and used in two modes. Classic or traditional visualizations were collected first and used to derive the model and the features of the framework through a bottom-up approach, by means of induction. The opposite process, deduction, was used for experimental visualization configurations. These visualizations have been constructed top-down with the model in place.

1.3.4 Structure of this work

The thesis has been divided into five main parts, ranging from Chapter 2 to Chapter 6. Chapter 2 presents the state of the art and related and relevant body of work. The core Chapters 3 – 5 lay out the model of the visualization process. They follow the stages of the visualization pipeline. Chapter 3 is dedicated to the data side, Chapter 4 to the visualization side, and Chapter 5 to the mapping of the two. Figure 1.1 shows how the chapters relate to the visualization pipeline and how they are structured.

Each of the three core parts follows a similar outline. First, the informal and formal model for simple (a) and complex (b) instances of the stage are developed successively. Second, the interfaces to the neighbouring stages are looked at closely (c). Finally, a quantitative view of the stage is unfolded (d). Accordingly, there are different ways to read the core chapters: either along a particular stage in the pipeline, or across the whole pipeline and along a certain aspect—for example, the sections about the formal model only.

The final chapter, Chapter 6, presents a potential architecture for a system according to this model and a prototype implementation. Furthermore, it contains a discussion of

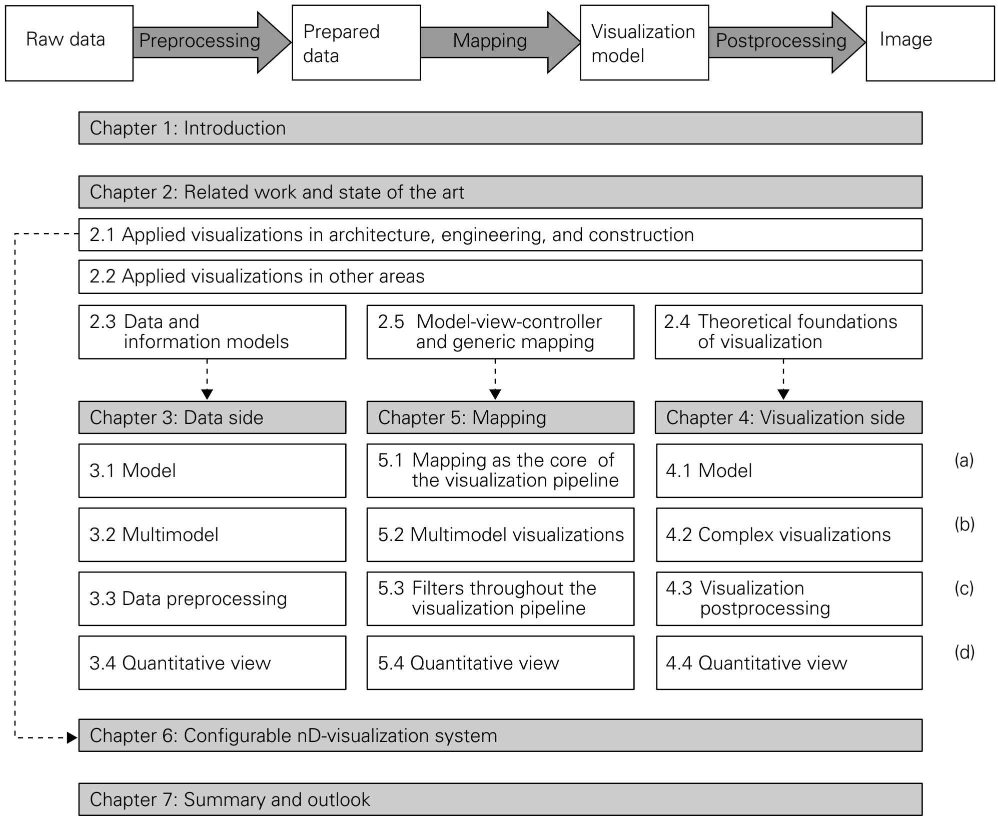

Figure 1.1: Structure of the work along the visualization pipeline

potential application areas of a visualization specification and a visualization generation framework for the field of architecture and construction.