Construction project management using digital models: construction cost estimation in early project phases

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Key words: construction project management, construction cost estimation, building information modeling

SUMMARY

Construction project management is one of the keys to economic and resource-efficient project success and supports project participants in strategic project decisions already in early project phases. Especially for costs and schedules, digital building models are a gain within Building Information Modeling supported projects. However, with the focus on model-based cost estimation, process difficulties repeatedly occur in the workflows. In order to determine their causes, the entire cost estimation process is examined by means of expert surveys. The interviews are then evaluated using a qualitative content analysis. The results show that software-based barriers exist, including insufficient software-neutral exchange formats and cross-interface software solutions. Furthermore, there are data-based barriers, which are caused by a lack of information exchange between the participants and a lack of standardization of the model contents. This in turn results in a lack of data quality in the cost planning process. This study serves to classify and improve the model-based cost planning process in model-based construction projects. It identifies causes for barriers and interruptions and, as a consequence, recommendations for their avoidance and for a better process quality can be derived.

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1. INTRODUCTION

1.1 INITIAL SITUATION

The key to successful construction project management is the adherence to cost, schedule and quality targets. (Bahlau und Klemt-Albert 2018) Project planning is a repetitive process in which participants develop, review and revise solutions until an optimal project concept is created. The term 'BIM', which is often used in connection with construction project management, stands for Building Information Modeling (Deutsches Institut für Normung e.V. August 2019) and is the basis for model-based work in construction project management, in which digital building models are used as the central source of information (Leśniak et al. 2021). The use of a BIM model as a central source of information and knowledge or database, over the entire life cycle of a property, represents the essential difference to conventional project management. (Weist und Lenz) Since cost estimation makes a significant contribution to measuring the success of the project, this is highlighted in this research work in the context of construction project management. In particular, the cost estimation with the help of digital methods, the so-called model-based cost estimation, is put in focus. Embedded cost planning is carried out continuously and systematically across all service phases and ensures that the cost security of a construction project is guaranteed through continuous estimation, controlling and managing. (Bender und Stoy 2021)

In the context of the BIM method, cost estimation can be integrated very well in early project phases, since cost estimation in early project phases is element-oriented rather than execution-oriented due to the still missing construction information. Within the element-oriented approach, geometric and structural engineering contents are considered separately in the digital building models, which makes a comprehensible cost determination possible in early project phases. (Ruf 2021)

1.2 RESEARCH INTENTION

Increasing the degree of digitalization in construction projects and in construction project management the complexity of work processes and the importance of information exchange between stakeholders grows. The change from conventional to model-based cost estimation is part of this process. In the current development, various process difficulties can be found in the workflow. These include insufficiently defined information requirements for the digital building model (Hasan und Rasheed 2019), lack of software compatibility, lack of standards

on the data content of digital building models (Stanley und Thurnell 2014), and also a lack of process flow structure (Yao et al. 2020).

The aim of this paper is to identify the process difficulties as well as their causes. This should serve as support for a comparable, structured overall process flow of cost estimation within model-based construction projects.

2. EXISTING RESEARCH

In order to ensure the topicality of research and its integration into model-based development of construction projects, it is useful to map the state of research of project management with BIM and also conventional and model-based cost estimation.

Author/Editor (Year)	**Place of publication**	**Title**	**Relevance to content**
Bahnert et al. (2021)	Germany	Planungsleistungen und Honorare mit BIM	Model-based projects and HOAI, planning processes
Ekung et al. (2021)	Nigeria	Critical Risks to Construction Cost Estimation	Risk factors, cost estimation
Kalusche (2021)	Germany	BKI Handbuch Kostenplanung im Hochbau	Basics / Procedure Cost Planning
Kuzminykh et al. (2021)	UK	4D and 5D Design Processes Automation Using Databases, Classification and Applied Programming	Cost model, automated cost estimation, classifications
Leśniak (2021)	Poland	Barriers to BIM Implementation in Architecture, Construction, and Engineering Projects – The Polish Study	Barriers to BIM implementation
Li et al. (2021)	China	Utilization of BIM in the Construction of a Submarine Tunnel: A Case Study in Xiamen City, China	Application and testing of the digital building model

Nguyen et al. (2021)	Vietnam	A Case Study of BIM Application in a Public Construction Project Management Unit in Vietnam: Lessons Learned and Organizational Changes	Implementation of BIM and project management, influence of BIM on project management
Sbiti et al. (2021)	France	Toward BIM and LPS Data Integration for Lean Site Project Management: A State-of-the-Art Review and Recommendations	Project management and BIM, current developments
Siemon et al. (2021)	Germany	Baukostenplanung und -steuerung – bei Neu- und Umbauten	Specifications for cost estimation, project participants
Ying et al. (2021)	China	Research on Project Management Computer System Based on BIM	Use of computer-based project management systems
Aitbayeva, Hossain (2020)	Kazakhstan	Building Information Model (BIM) Implementation in Perspective of Kazakhstan: Opportunities and Barriers	Barriers to the implementation of BIM
Farooq et al. (2020)	Pakistan	Investigating BIM Implementation Barriers and Issues in Pakistan Using ISM Approach	Barriers to the implementation of BIM
Muratova, Ptukhina (2020)	Russia	BIM as an Instrument of a Conceptual Project Cost Estimation	Modelbased cost estimation process
Yao et al. (2020)	China	Barriers of 5D BIM Implementation in Prefabrication Construction of Buildings	Barriers to the implementation of model-based cost planning

Clark, Alzraiee (2019)	USA	A Framework For Cost Estimation Using BIM Object Parameters	Structuring of the digital building model
Hasan, Rasheed (2019)	Iraq	The Benefits of and Challenges to Implement 5D BIM in Construction Industry	Barriers to the implementation of model-based cost planning
Mayouf et al. (2019)	UK	5D BIM: an investigation into the integration of quantity surveyors within the BIM process	Model-based quantity takeoff
Khan et al. (2018)	India	Evaluating Benefits of Building Information Modelling (BIM) Using A 5D Model for Construction Project	Advantages of model-based cost planning
Ramírez-Sáenz et al. (2018)	Columbia	Requirements for a BIM execution plan (BEP): a proposal for application in Colombia	Information content of the digital building model
Kovacic et al. (2014)	Austria	Assessment of BIM Potentials in Interdisciplinary Planning through Student Experiment and Practical Case Study	Interdisciplinary planning in model-based projects
Stanley, Thurnell (2014)	New Zealand	The benefits of, and barriers to, implementation of 5D BIM for quantity surveying in New Zealand	Barriers to the implementation of model-based cost planning
Seifert, Preussner (2013)	Deutschland	Baukostenplanung - Kostenermittlungen, Kostenkontrolle, Kostensteuerung, Haftung bei der Kostenplanung	Cost estimation stages, cost estimation, cost parameters, process flow

Stoy et al. (2012)	Deutschland	A concept for developing construction element cost models for German residential building projects	Cost estimation, construction cost elements
Eastman et al. (2011)	USA	BIM handbook – A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors	Basics of model-based work

Tabel 1: Current state of research

3. METHODS

The present research deals with the identification of process difficulties of model-based cost estimation as a task of project management. The research aims to shed light on the issue regarding the occurrence of process difficulties and process barriers as well as their causes. To make this possible, a questionnaire for expert interviews is used. The questionnaire is based on a literature review and will first be tested in a pilot round. In a first part, it contains questions on the subject expertise of the participants and in a second part, subject-specific questions, including open and closed questions, are asked about challenges of model-based costing as well as process difficulties.

Using the questionnaire as an interview guide, the expert survey is conducted in which the persons with subject matter expertise answer the closed questions as well as the open questions with room for concretization. The results are evaluated by means of a qualitative content analysis. In the process, a system of categories is formed that elicits the specific process difficulties and process barriers.

3.1 Questionnaire

In the expert survey, stakeholders in Germany and Switzerland are interviewed in order to determine which process difficulties exist in the cost estimation process. The questionnaire is based on the contents and components of model-based project management and cost estimation determined in a literature research.

The determined questionnaire, which at the same time functions as an interview guide, contains open and closed questions. It is divided into Part A (3 questions on the activities of the experts interviewed) and Part B (15 subject-specific questions). At the beginning, the persons with subject expertise are asked questions about their professional qualification and professional activity as well as open-ended questions about the delimitation of expert

knowledge in the chosen research field. Part B of the questionnaire starts with (semi-)open questions on reasons for using model-based costing and its challenges. Here, initial process difficulties are identified. The questions that follow serve to provide more detail in answering the research question.

The following questions are the core questions to answer the research question about process difficulties:

- What are the challenges in model-based cost planning?

Challenges identified from the literature are enumerated and reviewed:

- Additional effort

- Communication

- Information acquisition (Mayouf et al. 2019)

- data structures/data management (Hasan und Rasheed 2019)

- standardized quantity takeoff (Stanley und Thurnell 2014)

- suitable tools

- employees' willingness to innovate (Hasan und Rasheed 2019).

The respondents rated these statements according to their expertise as ‚1 = less important', ‚3 = averagely important' or ‚5 = very important'.

- What problems/process gaps currently exist?

- What fundamentals are needed in BIM-based construction projects to ensure effective model-based cost planning?

At the end of the questionnaire, participants have the opportunity to provide their own additions and feedback on the completeness and precision of the questionnaire.

3.2 Expert interviews

3.2.1 Selection of persons for the survey

The selected persons participate based on their practical experience in construction project management in general and specifically in model-based costing.

There are 9 persons from Germany and Switzerland participating, representing a cross-section of activities from the following areas: Planning companies, executing construction companies, construction economics companies and specialized cost estimation.

3.2.2 Procedure for expert interviews

Participants were contacted by telephone or email. The expert interviews are conducted to give the opportunity for concretizations by the participants. In addition, the wording of questions can be clarified and the interviewer can check that the questions have been interpreted as desired. The anonymity of the participants is guaranteed and the answers are treated confidentially.

3.2.3 Pilot round

In a pilot round, the questions identified in paragraph 3.1 are tested to ensure that the content identified is suitable for answering the research question. During the survey, it is found that some questions were not precise enough and lacked clear delineation.

- Therefore, for the closed questions, the rating is changed to ‚1 = not true', ‚3 = neutral' and ‚5 = true' in favor of comprehensibility.

- In reviewing the question on challenges, it is noted that the list of responses from the literature is not complete. The clarified and revised list now provides for the following supplemental response options:

- Liability risks related to the digital construction model,

- Lack of data quality,

- Interface coordination,

- Unclear process flows (Mayouf et al. 2019).

In addition, the following formulations are changed in favor of a generally valid view:

- "software solution (tool)" instead of "suitable tools (for example, software)"

- "Standardization/standardization is missing" instead of "standardized quantity takeoff"

3.2.4 Transcription

All expert interviews are recorded and then transcribed, which allows for accurate response analysis and should reduce bias.

3.3 Qualitative content analysis

All open-ended questions are analyzed using qualitative content analysis according to Mayring. This method originates from empirical social research and with it a procedure of qualitatively oriented text analysis is available, which can handle large amounts of material with the technical know-how of quantitative content analysis, but remains qualitative-interpretative in the first step and thus can also capture latent meaning." (Mayring und Fenzl 2019)

3.3.1 Procedure

For the present research, the following process model is chosen based on Mayring:

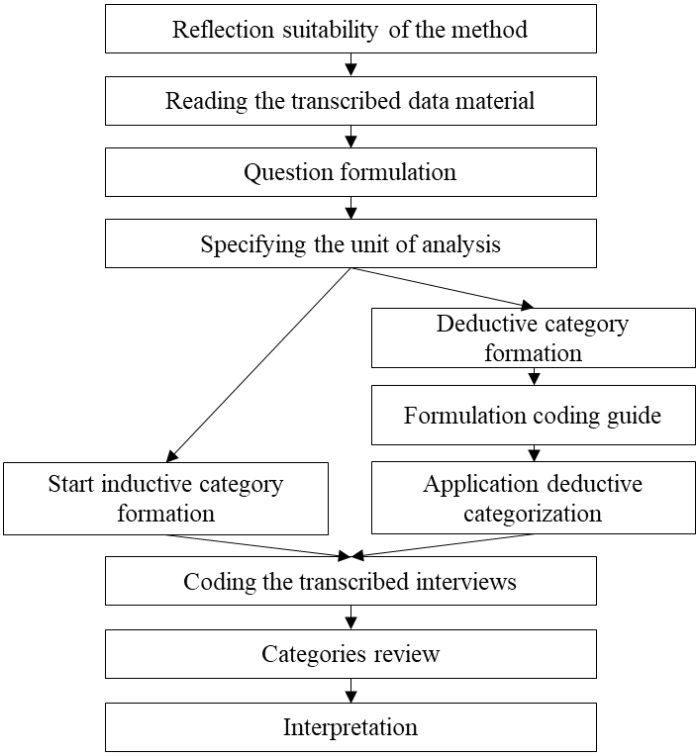

Figure 1: Sequence of qualitative content analysis (Mayring 2015)

After qualitative content analysis is found to be appropriate, the data material is read. The research question is derived from the research question of this research paper. The interviews are each to be seen as a unit of analysis. The coding unit is parts of the text, single words, paragraphs or sentences. First, deductive category formation is then conducted based on the literature review. Each category is defined in the coding guide and backed up with a textual example. Subsequently, the deductive categories are supplemented by inductive categories from the survey. The statements of the participants can thus be assigned to individual categories. The evaluation is carried out as a longitudinal evaluation per survey.

3.3.2 Category formation and coding guide

First, the deductive categories are formed from the previous research considering the expert interviews, while the inductive categories are directly formulated in the material from the text passages.

Category	**Definition**	**Example from survey**	**Coding rule**
Lack of standardization (Mayouf et al. 2019)	Lack of standardization and norming in process design	Norming, standardization and software solution, there I consider, after everything we have seen so far, everything to be so grotesquely bad	Mention of lack of standardization and norming, which leads to process flows that do not function smoothly.
Data quality (Yao et al. 2020)	Lack of completeness and quality of data in digital building models	The data quality, however, that is the biggest challenge, so with external parties above all.	Mention of poor data quality leading to process flows that do not function smoothly
Software-neutral exchange format (Deutsches Institut für Normung e.V.)	Software-independent collaboration makes it possible to use a freely chosen software product	The IFC interface, I find, leaves a lot to be desired, because I simply cannot take over all attributes by far with the current IFC interface	Naming/description of software-neutral exchange formats for e.g. project processing with openBIM
Process interruption	Process component that is not integrated into the model-based process flow with the DBM as the central source of information	We're just not doing that at the moment, because that's where we want to get to, that we can control costs.	Explicit mention of operations or process components that are not included in the model-based process flow and are not linked to the DBM as a central source of information

Difficulty in process flow	Reason for process flows not running smoothly - only possible with significantly more effort	The data quality, however, that is the biggest challenge, so with external parties above all.	Naming of challenges that lead to difficulties in process flow
Data quality as a process difficulty	Process flows that do not function smoothly and are caused by poor data quality	Poor data quality definitely.	Citing data quality as a challenge or difficulty that impacts process flow
Information procurement/coordination as a process difficulty	Process flows that do not function smoothly and are caused by faulty information procurement or information coordination	this is often the case that simply at the time when the first documents are created, such things are not yet defined at all	Naming of information procurement or information coordination as a challenge or difficulty that has an influence on the process flow
Lack of standardization and standardization as a process difficulty	Processes that do not function smoothly and are caused by a lack of standardization and standardization	So what, I think, would give a huge added value is, if you typify now, a uniform material catalog.	Mention of lack of standardization as a challenge/difficulty; Mention of desire for standardization.
Cross-interface software solutions as a process difficulty	Process flows that do not function smoothly and are caused by a lack of cross-interface software solutions	Well, I would imagine a software solution that is truly end-to-end.	Citing lack of cross-interface software solutions as a challenge or difficulty that impacts process flow
Specialist planner model as a process interruption	Specialist planner model that is not integrated into the model-based process flow as a source of information		

Tabel 2: Coding guide - deductive and inductive categories

Categories represent aspects of analysis as short formulations, are more or less closely oriented in formulation to the source material, and may be hierarchically ordered (upper and lower categories) (Mayring und Fenzl 2019), which is why the deductive and inductive categories identified are divided into main categories and subcategories.

Main category	**Subcategory**
Difficulties in the process flow	Software-neutral exchange format
	Data quality
	Cross-interface software solutions
	Lack of standardization
	Information procurement / coordination
Process interruption	Specialist planner model

Tabel 3: Category system - main categories and subcategories

4. DISCUSSION

As a result of the evaluation, it can first be stated that a distinction must be made between process difficulties and process interruptions. The process difficulty justifies a not frictionless process with additional effort, whereby the process can still be carried out model-based. In contrast, the process interruption represents a process component that does not integrate the digital building model as a central source of information.

Interviewees indicate that software-neutral exchange formats present a difficulty in the process flow. Despite standardized exchange formats, state of the art today IFC 4, there is missing information in openBIM projects. The lack of data quality of the digital building model to be used for cost determination is also a challenge in the process. This problem arises mainly at the beginning of the project due to the lack of standardization and norming for the creation of digital building models in general and in relation to the use case of cost determination. Difficulties in obtaining and reconciling information for the building models also arise at an early stage. Both the lack of normalization and standardization and the inadequate information procurement and coordination have an impact on the data quality of the digital building models and thus on all subsequent process steps. The possibility to use cross-interface software solutions is not always given frictionless in practice. However, the participants in the expert survey state that this difficulty is countered by isolated solutions and that the process is not interrupted as a result.

The participants stated that the process is interrupted by the integration of specialist models. On the one hand, the availability of the corresponding digital specialist models is not required as standard in the process, and on the other hand, the data quality is often poor due to a lack of standards. In addition, a distinction can be made among the specialist models as to whether the costs can be allocated on the basis of elements or not. The element-based cost estimations

are used, for example, for civil engineering details or landscape architecture, while cost estimations with digital specialist models of heating or ventilation engineers are rather not element-based. Participants indicate that there is no full integration of digital subject models for the process of cost estimations.

In this research, it is evident that both process difficulties and process interruptions exist in the model-based cost determination process. Software-based process difficulties primarily include the use of software-neutral exchange formats and cross-interface software solutions. The non-software-based difficulties mainly include the lack of data quality of digital building models. This, in turn, results from a lack of norming and standardization as well as a lack of information procurement and coordination. A process interruption is the complete integration of digital specialist models.

5. FUTURE STEPS

In order to deepen the present research, the standardization and normalization of process flows and contents should be mentioned first. This should ensure data quality and improve information procurement and coordination. It must be clarified which information must be available at which point in the process and in what level of detail in order to enable a standardized, comparable process. In addition, IT-oriented research regarding software-neutral exchange formats and cross-interface software solutions may also be of interest to enable a smooth process flow from a technical perspective.

Another addition to the present research is the definition of the process difficulties and interruptions for model-based cost control and cost management. These processes complete the process of model-based cost planning.

Fundamental is also a study on the early implementation of cost estimation in particular and cost planning in general in the overall context of model-based project processes relevant. Here, the question can be considered which mechanisms enable and improve the early integration of model-based cost planning as an important project success factor.

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