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Status quo of BIM implementation in hospital construction: a systematic literature review

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Hospitals are considered as highly complex critical infrastructure buildings due to their size and significant usage. Therefore, a high level of communication and coordination of all stakeholders and tasks is required to accomplish efficient building management throughout the entire life cycle of the hospital construction. Particularly in complex buildings where many stakeholders are involved in construction measures and higher requirements need to be fulfilled, the digital method Building Information Modeling (BIM) provides various potential advantages. This paper considers BIM as a solution approach and analyzes the status quo of implementation in hospital buildings. The focus is on systematically identifying literature that presents well-founded and current approaches to this topic and analyze the applications. Using a qualitative evaluation of the chosen literature, this study demonstrates the scope of BIM application in hospital construction as well as the improvement that can be achieved in project execution and building management over the entire life cycle. It is noticeable that BIM is already being used in many international hospital projects, with an upward trend. This finding can be explained by the many advantages of BIM-driven project management. In this context, the international BIM implementation status in hospital construction is elaborated and exemplarily compared with the status quo in Germany.

Keywords: Building Information Modeling, BIM, Hospital Construction, Digitalization in Hospitals, Construction Management, Project Management, Digitalization, Optimization, Critical Infrastructure.

1. Introduction

1.1 Issue

The architecture, engineering, and construction (AEC) industry is undergoing transformation driven by digital advancements, with a particular emphasis on the digital method of Building Information Modeling (BIM) (Ebbecke and Rhein, 2019, p. 165). The use of BIM provides enhanced planning certainty, especially for large and complex construction projects such as those in the healthcare sector.

Hospitals are highly complex structures, posing significant challenges for project participants (Holzhausen et al., 2015). Due to the type of their use, hospitals have high requirements that need to be considered in the design process. Additionally, effective communication and collaboration with stakeholders such as doctors and nurses are necessary to ensure optimal operations. Various building trades, including medical, laboratory, and supply technology, further contribute to the project's interfaces, thereby increasing the potential for errors.

1.2 Purpose

The use of digital methods in hospital construction aims to significantly reduce interface errors, unstructured planning processes, missing schedule and cost information, communication

gaps, and ambiguities among the various disciplines involved in the design and construction phases. Furthermore, the application of BIM throughout the entire lifecycle is expected to contribute to substantial cost savings in the maintenance of hospital facilities. (Hartmann et al., 2023)

The present study is carried out within the research project KlinikBIM, which aims to create a guideline for the implementation of BIM in hospital construction in Germany. To develop actionable recommendations, it is necessary to analyze not only the national status quo but also the international status quo. This approach allows for the incorporation of findings from countries that are more advanced in BIM application than Germany in the development of the guideline. Accordingly, both the status quo in Germany and internationally are analyzed and compared. The objective of this study is to analyze and evaluate the current state of research regarding BIM in hospital construction in order to consider the latest research findings in the future implementation of BIM in hospital construction.

2. Methodology

To capture the status quo of BIM implementation in hospital construction, a systematic literature research is being conducted. A prerequisite for a structured approach is an adequate selection of keywords as well as their combinations, which change and are recombined during the search process. This dynamic and iterative approach to keyword selection allows for the identification of relevant literature through the combination of frequently occurring keywords. In the initial step, an unsystematic literature search was conducted using Google Scholar and general web searches to gain insights into the topic and establish initial criteria. This facilitated the optimal selection of suitable keywords and their combinations.

During the process, it was quickly realized that there is currently no literature specifically addressing the topic of deconstruction and BIM in the context of hospitals or healthcare buildings. As a result, the term "deconstruction" was excluded from the keywords, while the other life cycle phases of the building (planning, construction, and operation and maintenance) were used as keywords. In Appendix Figure 2, the keywords used in this study are listed, along with the Boolean operators used. Additionally, the research was restricted to a specific time period. To ensure a contemporary overview of the topic, only sources published up until 2014 were considered. This timeframe was chosen because there has been a significant increase in relevant literature since 2014, reflecting the technical progress in the advancement of the BIM method in subsequent years.

Using the selected keywords and their combinations, the next step involved searching for relevant sources in the selected databases. The three databases used for this purpose were Scopus, ScienceDirect, and Web of Science. Duplicate sources from the search were excluded.

The systematic literature analysis was conducted for international literature (in terms of English-language literature) since it was determined during the unsystematic literature analysis that the number of German literature on the topic of BIM in hospital construction is insufficient to capture the status quo. The international expansion of the literature search provides the advantage of incorporating not only German experiences but also insights from other countries into the KlinikBIM guideline.

The literature obtained through this process consisted of a wide range of papers that address the topic of BIM implementation in hospital construction. In this study, only the most relevant sources from the research results are described. The search process of the systematic literature analysis is illustrated graphically in the results section.

3. Results

The described process of systematic literature analysis resulted in a total of 42 hits in the international search. Figure 1 illustrates the step-by-step approach of the systematic literature search, as described in the methodology section, along with the corresponding number of hits and outcomes.

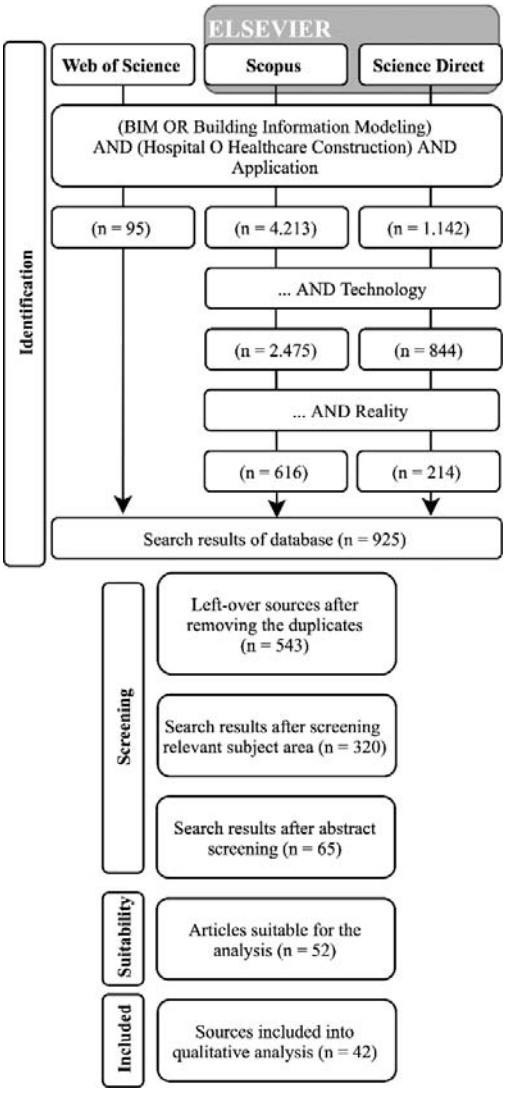

Fig. 1. Visuelle Darstellung des systematischen Suchprozesses am Beispiel der internationalen Literaturrecherche

In this chapter, a selection of these 42 hits is described, which the authors considered most relevant to provide an overview of the current status of BIM implementation in hospital construction. First, however, the overview of the German literature found is given. Although only five relevant sources were found, the authors consider them significant for the status quo of BIM in hospital construction. The comparison between German and international literature is particularly important for the development of the KlinikBIM guideline, as mentioned earlier. Therefore, this chapter is divided into sections presenting relevant German and international literature. This is presented in tabular form in both cases.

3.1 Literature from Germany

Table 1 presents the German literature that was deemed relevant for this study, including author(s), title, and sorted by publication year. The titles are translated from German to English in the table, while the original German titles are provided in the references. Following the tabular overview, a summary of the content of each publication is provided.

Table 1. Relevant German literature

Year	Author(s)	Title (translated to English)
2022	Riello, Nguyen	Fire protection design of the installation technology at the Cantonal Hospital Baden
2021	Albrecht et al.	Medical technology design with BIM: New ways to new targets
2020	Expert group “BIM in hospital construction” in bS-Ger.	Hospital information requirements: Fundamentals for the application of BIM in hospital construction
2019	Ebbecke, Rein	Building Information Modeling – The new DNA for construction projects. Just a trend topic or a paradigm shift for design?
2015	Holzhausen et al.	Future. Clinic. Construction: Strategic planning of hospitals

Riello and Nguyen (2022) discuss the benefits of interdisciplinary planning of modular support systems using BIM, exemplified by the Baden Cantonal Hospital. The article also highlights their interpretation in case of fire incidents. Reasons are provided why the application of BIM is advisable

in the case of interdisciplinary planning and coordination of the building trades involved.

The study by Albrecht et al. (2021) addresses a key issue in the design of hospitals and their medical equipment using BIM. In medical technology, a significant part of the devices used in a hospital cannot be represented in three dimensions, which necessitates the creation of a separate database in addition to the digital model. This database should contain all the technical information and costs necessary for the complete planning of medical equipment and needs to be available to the design department for interdisciplinary collaboration.

The expert group "BIM in hospital construction" of buildingSMART Germany (2020) defined hospital information requirements for the application of BIM. The publication provides guidance on which parts of the BIM technology the client intends to use for the specific construction project and assists in identifying the most qualified experts for the task. It serves as a framework to establish a transparent and trust-based foundation for all stakeholders involved in the design process, enabling the effective implementation of complex techniques.

The article by Ebbecke and Rein (2019) is about the benefits of using BIM across projects in the construction of hospital buildings. The authors highlight the potential of cross-border collaboration among all planners using a shared BIM building model, illustrated through the pre-preliminary design phase of the Weilerbach US Hospital in Germany.

In the book "Zukunft. Klinik. Bau" by Holzhausen et al. (2015), the challenges faced by hospital management in the future and how to address them are explained. The authors develop various approaches to strategic planning systems that enable more sustainable implementation of process flows and building structures in hospital construction. While the handbook does not directly refer to the application of BIM methodology, the tools and mechanisms presented in this source can provide insights into the opportunities and challenges of successful BIM implementation in hospital construction. These tools and mechanisms support a modern, contemporary, and innovative approach to hospital planning.

Based on the listed German literature, a comprehensive representation of the current status of BIM implementation in hospital construction cannot be achieved. Therefore, the literature analysis needs to be supplemented with international research. The the results are presented in the following chapter.

3.2 International literature

In table 2, the English-language literature, which has been deemed most relevant, is listed in addition to the German literature from the previous chapter.

Table 2. Relevant international literature

Year	Author(s)	Title
2022	Wang	Application of BIM Technology in Hospital Engineering Project
2021	Zhen	Application and Innovation of BIM Technology in Construction Management Stage of Large Medical Construction Projects
2021	Chen et al.	Modular composite building in urgent emergency engineering projects: A case study of accelerated design and construction of Wuhan Thunder God Mountain/Leishenshan hospital to COVID-19 pandemic
2020	Petersen et al.	Leveraging on Enterprise Building Information Models in Health Care Services: The Case of St. Olav University Hospital
2020	Akçay et al.	A Public BIM Project: Cerrahpaşa Healthcare and Education Facility

2018	Lin et al.	Integrated BIM, game engine and VR technologies for healthcare design: A case study in cancer hospital.
2017	Holten Møller, Bansler	Building Information Modeling: The dream of perfect information
2015	Merschbrock, Munkvold	Effective digital collaboration in the construction industry – A case study of BIM deployment in a hospital construction project

In Wang's study (2022), the expansion project of an outpatient station in a hospital in Henan province, China, is examined to illustrate the utilization of BIM technologies in the planning and construction processes. Specifically, the focus is on collision detection and the creation of a virtual construction site using BIM. The study provides an overview of the advantages of applying BIM technologies in medical construction projects.

Zhen (2021) explains how the use of BIM technologies contributed to the improvement of the new University Hospital of Dalian Medical University in China. For example, by deriving three-dimensional formwork and reinforcement plans from the digital model, it was possible to significantly facilitate the realization of individual positions.

Chen et al. (2021) describe how BIM, combined with modular construction methods, played a vital role in the rapid realization of two healthcare facilities, the Huoshenshan Hospital and Leishenshan Hospital, in Wuhan, China, in response to the Covid-19 outbreak in 2019. The article highlights how BIM facilitated and accelerated the planning and construction of one of the emergency hospitals, the Leishenshan Hospital, emphasizing the use of modular construction techniques coordinated and realized through BIM.

Peterson et al. (2020) discuss the utilization of BIM in hospitals to support the operational phase. The authors explore the concept of Enterprise BIM at St. Olav University Hospital in Norway, aiming to enhance the operation and maintenance phase of the facility. BIM models were integrated with other data and information to achieve this objective.

The University Hospital of Istanbul-Cerrahpaşa, one of Turkey's largest healthcare projects, was executed as a pilot project using the BIM methodology, as described by Akçay et al. (2020). The authors outline how BIM was employed during the design stage of the hospital and the resulting benefits for the project.

Lin et al. (2018) shed light on a newly developed system that integrates BIM, game engine, and VR technologies to evaluate the design of a hospital in Taiwan. The focus of the study was to evaluate how these technologies can be used collaboratively to enhance the design process and improve the overall quality of healthcare facilities.

In the study by Holten Møller and Bansler (2017), the preliminary findings of a field study on a hospital construction project in Copenhagen, Denmark, are presented. The project involved planning and constructing a new main hospital building and renovating existing structures. Given the early stage of the project, the emphasis was placed on the role of BIM as a platform for collaboration among stakeholders, including clients, architects, engineers, and future users, to enhance the conceptual design.

Merschbrock and Munkvold (2015) describe the establishment of a shared data platform for a hospital construction project in Norway. The authors highlight the importance of interdisciplinary collaborative work throughout the project duration and provide a detailed explanation of the development of a cross-border server structure as an example.

4. Conclusion

Through a qualitative analysis of the literature, this research has demonstrated the current integration of Building Information Modeling (BIM) in

hospital construction and the extent to which it improves the planning, construction, and commissioning of such facilities. It is evident that BIM is already being utilized in a significant number of hospital projects, thanks to the numerous advantages demonstrated by pilot projects employing BIM-driven project delivery. The literature particularly emphasizes the potential benefits of BIM for the operation, management, and maintenance of healthcare facilities. Efficient Facility Management (FM) is crucial for hospitals to ensure high-quality and economically efficient healthcare services.

Digital methods can be considered accelerators for increased transparency, closer collaboration, and higher productivity in future healthcare construction projects. However, it is noteworthy that many construction companies still struggle to incorporate new technologies associated with BIM into their conventional workflows. The use of BIM in hospital construction is currently associated with significant investment costs for executing planning and construction firms.

Finding ways to facilitate construction companies in cost-effective and sustainable integration of BIM planning methodology into their established practices remains a challenge for future research. BIM offers numerous benefits for hospital construction, but it also requires early decision-making and a holistic project perspective. Planning, constructing, and operating hospitals entirely in a digital manner proves challenging at present, as not all project stakeholders possess the same level of BIM knowledge. The findings of this study indicate that the benefits outweigh the drawbacks and that the use of BIM as an accompanying planning methodology can be expected to increase in both national and international medical construction projects in the future, despite the need for further research.

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Appendix. Used keywords

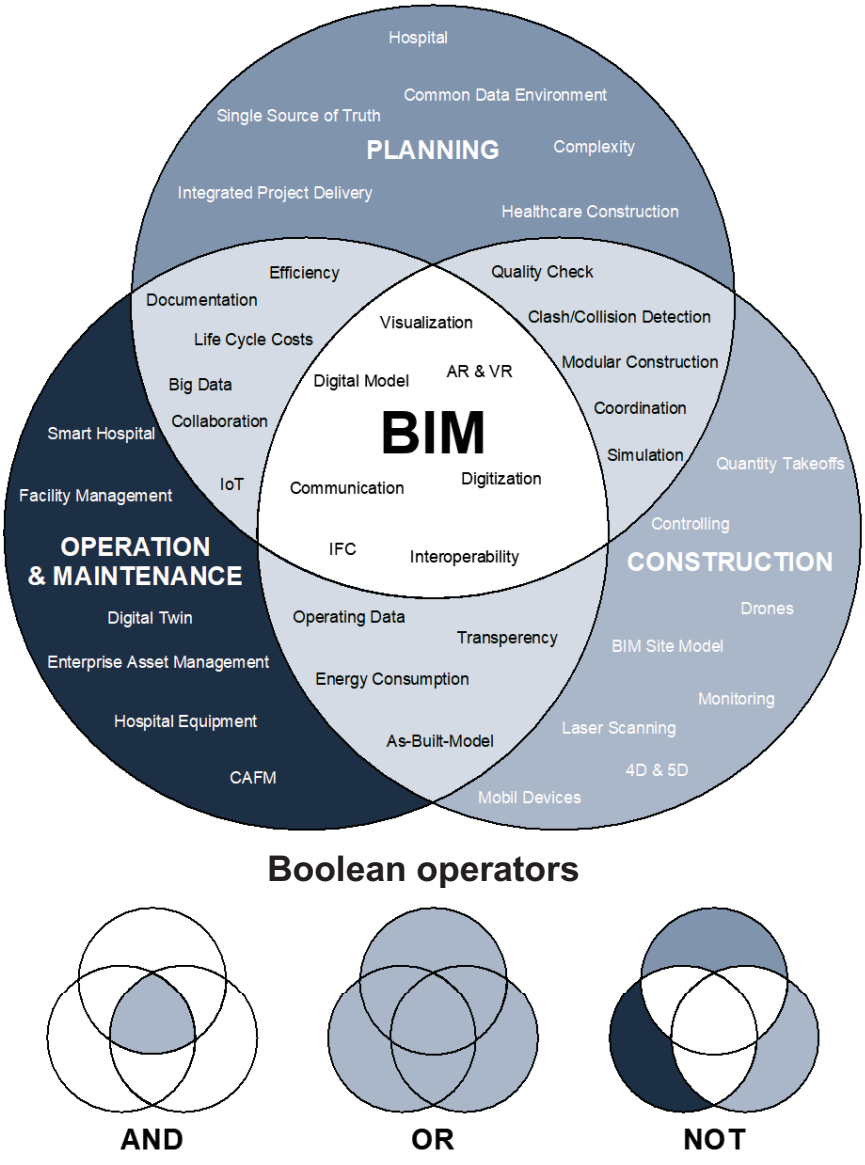

Fig. 2. Keywords used in this systematic literature research

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