

Explaining the Gap between the Promise and Practice of 5D BIM implementation

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Abstract—Cost management remains a challenge in the Architecture, Engineering, and Construction (AEC) industry, as cost estimation, budgeting, and control depend on fragmented information, heterogeneous stakeholder responsibilities, and discontinuous processes across the project life cycle. Although 5D BIM (Building Information Modelling) promises improved quantity take-off, cost visualization, and decision support, its practical implementation often falls short of the benefits demonstrated in isolated or experimental settings. This paper investigates why the continuous use of BIM for cost planning, cost estimating, and cost management has not yet become common practice. The study adopts a qualitative exploratory case study design based on semi-structured interviews with representatives of clients, designers, contractors, general contractors, and specialist firms in the context of German AEC industry. The empirical data were analysed using a deductive–inductive category system informed by the DeLone and McLean information systems success model. The findings show that technological advances in 5D BIM coexist with persistent discontinuities in cost management processes. In particular, limited reuse of model-based cost data and differences in the definition and interpretation of cost-relevant information restrict implementation across project phases and stakeholder boundaries. The paper contributes to product and process modelling in the built environment by explaining semantic interoperability as a central condition for integrating model-based information systems into practical cost management workflows.

Keywords—cost management; BIM implementation; information systems; exploratory case study; interoperability; German AEC industry.

I. INTRODUCTION

Cost management represents one of the most critical and challenging functions for the successful delivery of projects in the Architecture, Engineering, and Construction (AEC) industry. It includes the planning, estimation, budgeting, and control of costs to ensure financial viability and the achievement of project objectives [1]. These activities involve a wide range of stakeholders and span multiple project stages, from conceptual design and procurement to construction and project completion [2]. However, traditional cost estimation practices continue to face significant challenges, including limited information sharing and insufficient collaboration between design and construction teams [3]. As a result, cost overruns remain a persistent problem in construction projects worldwide [4].

To address these issues, Building Information Modelling (BIM) has been promoted as a key component of digital transformation in the AEC sector. Numerous studies have demonstrated the potential benefits of so-called 5D BIM, including improved communication through cost visualization [5], error reduction through automated quantity take-off [6], time savings [7], and better support for decision-making [8]. Nevertheless, limitations in model data quality [9], software compatibility [10], interoperability [11], and process integration [12] remain significant. Recent research continues to highlight challenges in integrating 5D BIM into existing workflows [10, 13, 45].

Despite growing scholarly interest, a persistent gap remains between the benefits demonstrated in controlled or isolated settings and the practical implementation of 5D BIM in real AEC project environments [14]. This paper seeks to explain the gap between the promise and the practice of 5D BIM implementation. It is situated within the field of technology implementation and draws on empirical evidence from a qualitative, exploratory case study in the German AEC industry.

The study examines the integration of the 5D BIM methodology into work processes related to cost planning, cost estimating, and cost management (see Fig. 1), with a particular focus on the relationships between the activities of different stakeholders, including clients, designers, contractors, general contractors, and specialist firms [29]. The main objective is to investigate whether the benefits of 5D BIM described in the research literature have already been realized in practice and whether 5D BIM information systems function effectively in real-world project settings. The paper provides a detailed account of the practical reality of 5D BIM implementation from the perspectives of stakeholders involved in a typical AEC project. This in-depth analysis contributes to a better understanding of current implementation challenges and supports the further development of sustainable solutions for the use of information technologies, such as BIM, in the AEC industry.



Fig. 1. Control loop “Cost planning” according to DIN 276 [15].

The paper is structured as follows. Section II summarizes relevant work on the application of the 5D BIM methodology and on the implementation of technologies such as BIM. Section III explains the methodology used to achieve the research objective. Section IV presents the results using the analytical framework of information systems research. Section V discusses the findings in relation to the aim of the study. Finally, Section VI evaluates the contribution of the research, reflects on its limitations, and outlines opportunities for further research.

II. RELATED WORK

The concept of 5D BIM, first introduced in the research literature in 2008 [16], describes a collaborative project delivery process during the planning and construction phases that enables project costs to be estimated, monitored, and managed in a transparent and optimized manner. Use cases of 5D BIM are often classified under quantity take-off and cost estimation [2, 17]. Numerous studies have discussed the benefits of and barriers to 5D BIM implementation [5–12]. Since 2020, most research has focused on case studies related to cost estimation and cost control, as well as on adoption barriers in different national contexts [18–21].

Nast and Koch [2] investigated how the theoretical concepts of 5D BIM have so far been tested and implemented in real planning and construction projects in order to realize benefits in cost estimation. On the one hand, their findings indicate that the technical aspects of 5D BIM have been well explored in the context of technological implementation. On the other hand, although the use of 5D BIM by professionals is discussed in many research papers, greater attention should be paid to implementation processes and standards, particularly to the alignment between BIM-enabled opportunities and existing cost management practices [14, 23]. Moreover, many studies are conducted within specific, closed, or relatively isolated frameworks, which may limit their ability to fully capture the complexity of industrial practice and the interdependencies involved in decision-making by individual project stakeholders [22, 24].

It is noteworthy that even recent research continues to identify key challenges in the implementation of 5D BIM, particularly deficiencies in its integration into existing workflows [10, 13]. Existing studies do not provide deeper insight into how BIM is integrated into cost planning processes or why the continuous use of 5D BIM, despite its technological feasibility, has not yet become common practice [2, 14].

A systematic consideration of the BIM methodology focuses on the interaction between people, technology, and processes [17]. However, these positive aspects often remain detached from the specific implementation context, particularly when considering cost management processes supported by BIM [23]. As a result, it remains unclear how the broader socio-organizational context contributes to the configuration of the BIM information system or how this context can be adapted to achieve specific outcomes [24]. Consequently, the gap between theoretical 5D BIM concepts and their practical application remains insufficiently explored and explained, and may therefore widen further.

For the context-sensitive analysis of work systems such as BIM, concepts and theories from the discipline of information systems (IS) research are increasingly being applied [25, 26]. This approach also underpins the present study's investigation of BIM in cost planning, cost estimating, and cost management.

III. METHODOLOGY

The study adopts an exploratory, descriptive research design with the aim of understanding in detail the implementation process of the 5D BIM methodology, without examining causal relationships. The DeLone and McLean Success Model from IS research serves as the analytical framework and was previously applied by Dowsett and Harty to evaluate BIM implementation in two case studies [24]. The

IS Success Model [27] comprises six interrelated dimensions of success: Information Quality (IQ), System Quality (SQ), Service Quality (SeQ), Intention to Use and Use (IU), User Satisfaction (US), and Net Benefits (NB) (see Fig. 2). These dimensions serve as deductive main categories of the structured content analysis, supplemented by inductively derived subcategories from the collected data (see Tab. I).

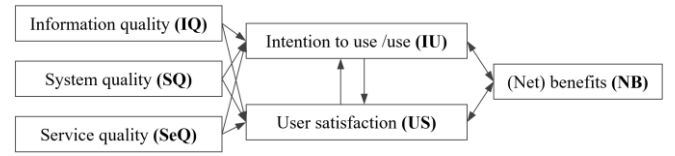


Fig. 2. Information Systems Success Model [27].

Deductive Main Categories	Inductive Subcategories
Information quality (IQ) represents a semantic success dimension of the information system; it serves to determine the success of the information within the planning and construction project; it comprises aspects of the information generated by the system that have contributed positively or negatively to project activities; it does not describe the technical properties of the IS.	IQ.1: Usefulness of the information IQ.2: Content IQ.3: Format IQ.4: Accuracy IQ.5: Completeness, consistency IQ.6: Uniformity, ease of understanding IQ.7: Correctness IQ.8: Relevance, timeliness IQ.9: Information management
System quality (SQ) represents a technical success dimension of the information system and is a measure of the information processing system itself (e.g. definition of compatibility, output quality, etc.); it reflects the capability of BIM authoring software and tools that influence reliability and usability; the usability and performance characteristics of an information system are determined by the desired properties of that system; it shows how suitable the technology is for supporting and facilitating project tasks; it does not assess service quality.	SQ.1: Usability SQ.2: Object manipulation SQ.3: Linking cost data and model SQ.4: Reusability [templates] SQ.5: Reliability SQ.6: Flexibility [adaptability] SQ.7: Compatibility [transferability] SQ.8: Interoperability SQ.9: Closed vs. Open BIM SQ.10: Process automation SQ.11: Output quality, data quality SQ.12: System implementation SQ.13: System development SQ.14: System logic SQ.15: Performance, response time
Service quality (SeQ) represents a non-technical success dimension of the information system and is a measure of the effectiveness of the non-technical infrastructure (e.g. support from clients and owners for BIM implementation, training measures, contractual requirements, etc.); it describes the degree of overall efficiency of an information system and its associated internal and external support structures; it includes conceptual aspects of the information system that lead to the reconfiguration of the old system; it does not assess technical quality.	SeQ.1: procurement law and process SeQ.2: Contracts, normative aspects SeQ.3: Motivation, acceptance SeQ.4: Education, continuing education, training SeQ.5: Business model SeQ.6: Roles and functions SeQ.7: Change to existing processes SeQ.8: Harmonization SeQ.9: Client requirements SeQ.10: Material and time resources SeQ.11: Standardization SeQ.12: Structure of the construction industry SeQ.13: Management support
Intention to use / use (IU) represents the current and potential application of the output by project participants in different project phases and refers in each case to the specific 5D BIM application; it includes a participant's intention to use the 5D BIM system.	IU.1: Concept phase IU.2: Planning phase IU.3: Tendering and award of construction works IU.4: Construction phase IU.5: Across projects
User satisfaction (US) represents the recipient's response to the use of the output; it describes the fact that project participants prefer the technology in routine application over other traditional methods; it does not assess technical quality.	US.1: Effort-benefit ratio US.2: Task productivity US.3: 5D BIM workflow US.4: Conflicts of interest US.5: Communication efficiency
(Net) benefits (NB) represent the improvement of individual (project-related) and organizational performance and are a measure of the effects between clients and contractors [designers and constructors], as well as between companies and the construction industry; they describe organizational benefits at multiple levels: strategic, informational, and transactional; they do not assess implementation challenges.	NB.1: Traceability NB.2: Competitive advantage NB.3: Time savings NB.4: Collaborative cooperation NB.5: Early problem detection NB.6: Workload reduction NB.7: Reliable quantities NB.8: Higher planning quality NB.9: Information security NB.10: Customer focus / customer relationship

Table I. Categories in the Success Model for Implementing the 5D BIM Information System.

Data collection comprised the preparation, conduct, and transcription of expert interviews and forms the basis for the subsequent data analysis. In the preparation phase, experts were purposively recruited and a semi-structured interview guide with open-ended questions on the 5D BIM implementation was developed. The interview guide was created iteratively based on research literature and tested in two preceding pilot interviews. The interview questions included general information on BIM adoption within the company as well as specific questions on the application of BIM in cost planning and cost estimation processes.

The experts were recruited through existing networks of established BIM working groups. A purposive sampling approach according to Patton [28] was applied for the selection of data sources. Different perspectives were represented on the basis of typical constellations of project participants, such as clients, project developers, designers, contractors, general contractors, specialist firms, and component suppliers [29]. A prerequisite for selection was project experience with 5D BIM implementation and/or its further development within the company (see Tab. II).

Code	Project Role	Position	Professional Experience	Professional Background
B1	Designer	Management Board	>20 years	Construction management, design planning
B2	Designer	Structural engineering	>15 years	Construction supervision, cost estimation, tender
B3	Designer	Cost and schedule planning	>30 years	Quantity take-off, construction management, site management
B4	Designer	Architecture, project management	5 years	Architectural design, cost planning
B5	Specialist firm	Head of Digitalization Department	10 years	BIM implementation within the company
B6	General contractor	BIM management	>5 years	Architecture, cost estimation, project management
B7	Client	BIM consulting	20 years	Surveying, BIM consulting
B8.1 B8.2 B8.3	Designer	1.Management 2.Head of CAD 3.BIM application	25 years 30 years <5 years	Support of CAD systems, BIM, and BIM-based cost planning
B9	Contractor	Head of BIM Management und BIM Services	25 years	Site management, cost estimation, tendering, BIM implementation
B10.1 B10.2 B10.3	Designer	1.Management 2.Team lead 3.Project Engineer	20 years >15 years >5 years	Design and structural engineering in civil engineering
B11	Client	Project Manager for Software Applications	25 years	BIM implementation in client and contractor organizations, software consulting
B12	Contractor	Head of Building Services Engineering & Automation	30 years	IT, precast concrete industry, BIM implementation within the company
B13	General contractor	Development iTWO & Revit	<5 years	Software solutions in construction companies
B14	General contractor	Group Head of BIM for Building Construction	30 years	Work preparation, cost estimation, site management
B15	General contractor	Head of BIM, Innovation, and Digitalization Division	30 years	BIM application, project management, digitalization in construction

Table II. The anonymized data of the persons interviewed.

The interviews were conducted and digitally recorded between July 2022 and February 2023, lasting between 0.5 and 2.5 hours each. Data collection continued until no new insights emerged, resulting in 15 interviews with a total of 19 participants [46]. The approximately 20 hours of audio material were transcribed and anonymized.

The empirical material was analysed using structured content analysis based on a deductive–inductive category system [30]. Quality and validity were enhanced through triangulation, including the parallel analysis of the data by a second researcher. The data analysis is divided into six steps and follows an iterative procedure according to Kuckartz [30]: 1) Initial text work; 2) Development of thematic main categories and coding of the entire material; 3) Compilation of all text passages coded under the same main category; 4) Inductive derivation of subcategories from interview-based material; 5) Coding of the entire material using the differentiated category system; 6) Conducting analyses and creating visualizations.

With regard to the objectives of the study, the following forms of analysis were applied [30]: 1) category-based analysis along the main and subcategories (see Tab. I); 2) case-based thematic summaries; 3) contingency analysis to examine the relationships between categories.

The contingency analysis highlights positive and negative relationships between individual categories that significantly influence the success or failure of the 5D BIM information system. Compared with the original DeLone and McLean model [24, 27], clear connections emerge between information quality, system quality, and service quality (see Fig. 2). This may be explained by the fact that, in a successful 5D BIM system, these dimensions do not necessarily have to be developed to the same extent, but may partly compensate for one another. For example, high service quality can help overcome technical challenges related to system quality.

Individual subcategories within the main categories were particularly prominent in the interview data (see Fig. 3). Their interactions are summarized briefly in Table III. This represents an additional methodological contribution to research on technology implementation of BIM systems.

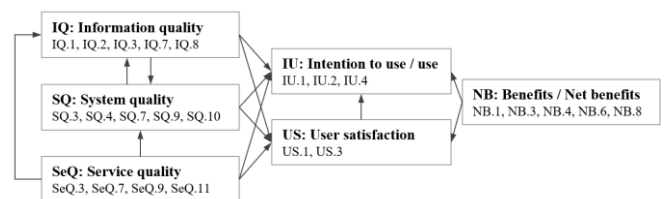


Fig. 3. Categories and their relationships in the study.

Subcategories	Type of Link	Subcategories	Type of Link
IQ.1 – SQ.2	unidirectional, (-)	SQ.8 – NB.4	unidirectional, (-)
IQ.8 – US.3	unidirectional, (+)	SQ.8 – IU.4	unidirectional, (-)
SeQ.11 – IQ.8	unidirectional, (+)	SeQ.9 – SQ.10	unidirectional, (+)
SeQ.9 & SeQ.11 – SQ.2	unidirectional, (+/-)	IQ.3 – SQ.9	bidirectional, (+/-)
SeQ.9 & IQ.6 – SQ.3	unidirectional, (+)	SeQ.1 & SeQ.11 – US.1 & US.2	unidirectional, (+)
SeQ.2 & IQ.8 – SQ.3	unidirectional, (+/-)	SQ.4 – SQ.10	unidirectional, (+/-)
IU.1 & IU.4 – US.1	bidirectional, (+/-)	SeQ.11 & SeQ.9 – SQ.9	unidirectional, (+)
IQ.2 – SQ.4	unidirectional, (+)	SeQ.9 – IU.4	unidirectional, (+/-)
IU.1 – SQ.4	unidirectional, (+/-)	IU.1 – IU.2	unidirectional, (+)
SQ.6 – SeQ.7 – SeQ.2	bidirectional, (+/-)		+ positive linkage - negative linkage

Table III. Pairs of inductive subcategories and their interaction.

IV. RESULTS

The interview data were divided into five interview sets according to project roles of the participants (cf. Section III): 1) clients, 2) designers, 3) contractors, 4) general contractors, and 5) specialist firms. The perspectives of the project participants are analysed using the main categories of the DeLone and McLean Success Model. In addition, practical insights into 5D BIM implementation are briefly compared between building construction and infrastructure projects.

Information Quality (IQ)

The IQ required for cost planning and cost estimation, as well as procedural optimization of workflows, is currently achieved predominantly only within closed BIM systems. Contractors and general contractors criticize the information quality of external models from designers and clients, because due to insufficient semantics and the limited editability of IFC (Industry Foundation Classes) files, these models cannot be directly reused for downstream processes. One interviewee noted that 5D BIM is therefore used only in standardized modular construction, because “... *no qualified models at all ... are available from external companies*” (cf. interview ref.: B12: 28). As a result, additional effort is required either to recreate estimating models or to subsequently attribute or manipulate external models.

The sustainable reuse of qualified 5D BIM models is therefore regarded as central in order to “... *avoid wasting time on remodelling [...] for construction cost estimation*” (cf. interview ref.: B11: 38). One public client aims to close this information gap through standardization and clear specifications of information requirements, including sample files and templates for linking Bill of Quantities (BoQ) items with standard building elements from component libraries (cf. interview ref.: B7: 67).

All respondents emphasize the need to provide relevant services and information at an early stage. At the same time, they point to structural challenges, particularly in infrastructure construction, where reliable modelling bases are often unavailable. This field is closely linked to existing built structures. In bridge construction, for example, rehabilitation or maintenance measures are frequently involved, and the actual condition may only become visible once demolition work has begun. Similarly, in railway and road construction projects, undocumented or incompletely documented utilities are often discovered only during excavation. Insufficient phase-appropriate information provision reduces the intention to use the 5D BIM system; timely delivery, adequate quality, and sufficient information depth for each project phase are therefore essential.

Effective 5D BIM information management depends on the continuous further development of model-based cost planning and cost control. One contractor suggested integrating the LOD attribute (Level of Development) into the IFC data model as a standardized attribute (cf. interview ref.: B12: 109). This attribute is intended to represent the development status of the model and to enable automated assignment to the respective stage of cost calculation. Once a higher level of development is reached, the LOD attribute should be updated accordingly so that the model can be automatically assigned to the appropriate cost structure template.

System Quality (SQ)

All project participants work with different software environments for processing their respective tasks. Little closed BIM is widespread due to the insufficient implementation of open interfaces and standards, such as the BIM BoQ container [31] and XML 3.3 in conjunction with CPIXML exchange (e.g. software such as RIB iTWO 5D and DESITE md pro). At the time of data collection, the IFC standard could not yet be fully used for cost planning. The attributes standardized in the IFC schema (version IFC 4.3) do not cover all required cost-relevant information. This information must therefore be added in property sets of the native formats. In addition, the entity `ifcCostItem` [32] cannot be used in common BIM software without additional programming effort.

The BIM BoQ container has not yet been fully implemented for import and export in common estimating programs. In this multi-model container, links are created between IFC objects and BoQ items in GAEB XML format (GAEB – Joint Committee on Electronics in Construction) [33]. In this way, the object-based structure of the building is linked to the established GAEB-based workflow [34]. Instead of an object-based BIM view, the conventional logic centred on the BoQ remains the dominant organizing principle.

Despite the potential of widely used 5D BIM software solutions described in [35], there is still a lack of the necessary flexibility and performance (cf. interview ref.: B13: 94). Calculation logics, such as lump-sum items, can only be represented to a limited extent, and individual technical work steps can be transferred to existing processes only with considerable effort. Contractors and designers criticize rigid mapping processes, since more flexible approaches are often better suited to implementing client-specific requirements. One interviewee emphasized the added value of a low-threshold mapping process that can also be used by non-IT users (cf. interview ref.: B14: 78).

Technical limitations in data processing restrict the scope and reusability of 5D templates and the achievable degree of automation. In addition, automated linking with AKVS (Instructions for cost estimation and budgeting of road construction measures) [36] and STLK (Standard specification catalogue for road and bridge construction) [37] proves to be error-prone because the information required for BIM is not provided consistently and continuously across the project (cf. interview ref.: B2). IQ and SQ are mutually dependent: technical capabilities (interfaces, templates) determine the quality of 5D information; conversely, timely available model-based information enables higher system quality through automation.

Service Quality (SeQ)

Public clients, as a key driver of BIM implementation, pursue the goal of compensating for deficiencies in information quality and system quality through higher service quality. The technical implementation of standardized information requirements in the sense of open BIM is achieved through sample or template files that represent software-independent links between standard building elements/objects, BoQ items, and costs (cf. interview ref.: B7 and B11). Contractors and designers attach great importance to clients' requirements (cf.

interview ref.: B15: 67). Heterogeneous requirements and non-BIM-compliant processes on the client's side increase effort and are particularly costly for small and medium-sized enterprises.

The transition from a drawing-based to an object-based way of working requires fundamental process adjustments, such as planning meetings based on BIM models and clear definitions of information content and of model and object structures. One interviewee accordingly described the approach less as "*BIM*" than as "*process and data integration*," and considered this term more appropriate (cf. interview ref.: B9: 23).

At the same time, project participants report that existing processes, contractual arrangements, and standards, especially in public-sector projects, are only compatible with the BIM methodology to a limited extent. Examples include the following: 1) established approval processes are still based on 2D drawings rather than BIM models; 2) billing under the VOB (Procurement and Contract Procedures for Construction Works) [38], which is designed for simplified quantity determination from 2D plans, makes BIM-compliant billing more difficult; 3) discrepancies between the required modelling depth and the requirements set out in specification texts such as STLB-Bau (Standard specification catalogue for construction) [39]; 4) award based on the lowest price (at least 75% of the decision), meaning that planning quality is inadequately taken into account; and 5) the HOAI (Fee Scale for Architects and Engineers) [40] does not adequately reflect the BIM-related effort incurred in design offices during work stages 1–4, whereas efficiency gains often only materialize in execution planning, as long as projects are only weakly standardized.

Importantly, the findings described above are embedded in the German regulatory and procurement context. Their transferability to other European settings therefore depends on comparable institutional conditions, including BIM mandates, procurement models, contractual arrangements, and the degree of stakeholder integration. In environments with mandatory BIM adoption or integrated project delivery arrangements, the relevance and relative importance of the identified SeQ shortcomings may differ.

User Satisfaction (US)

When contractors and general contractors are involved early in the tender phase, they are able to work on a model-based basis. However, price inquiries are still carried out conventionally via cost elements, because BIM-based procedures are currently considered not to be economically viable. Nevertheless, a functional specification in conjunction with the BIM methodology offers advantages for construction companies.

US with the 5D BIM system depends not only on software functionalities, but equally on the supporting non-technical infrastructure (SeQ), such as the acceptance of those involved, and correlates closely with the internal company objective of increasing efficiency through continuous process optimization. High information quality increases user satisfaction because it reduces rework and enables stable 5D workflows. Although purposefully configured closed BIM solutions promote intention to use and user satisfaction, they do not enable continuous cross-phase use.

Intention to Use and Use (IU)

The case study confirms the findings of previous research, such as [10, 12, 13], that the 5D BIM methodology is used primarily in the planning phase for quantity take-off, the preparation of bills of quantities, and cost estimation. In modular construction and in the use of standardized building elements from digital component libraries (e.g. modular construction in industrial and residential building, stopping points or service areas in infrastructure construction), the boundaries become blurred: for designers, between cost estimating and cost calculation; for contractors, between cost estimating and tender cost estimation.

It is noteworthy that 4D BIM, with its time component and the possibility of displaying current costs, had not been introduced operationally in any of the companies included in the case study. Instead, 5D BIM is prioritized because, in practice, quantities are first determined and costs are then calculated from them. Scheduling follows afterward. Detailed construction scheduling before contract award is regarded as impractical, which is why price issues are systematically addressed before time issues.

(Net) Benefits (NB)

The improvement of planning quality and thus cost certainty is pursued equally by all interviewees. Contractors and designers see BIM implementation as a competitive advantage. They focus on process optimization and quality assurance, irrespective of client's requirements. Contractors and general contractors in particular place value on time savings in tender preparation and on higher value creation through the reduction of routine tasks, such as preparing bills of quantities. By contrast, one specialist firm currently sees no advantages in cost planning within a closed BIM system. The recurring modelling effort proves to be a central obstacle due to the time involved (cf. interview ref: B5: 55).

Building Construction vs. Infrastructure

The concept phase is often insufficiently considered in both building construction and infrastructure projects due to the high effort required compared with conventional planning approaches. In infrastructure projects, it is often not possible to create a schematic model for cost estimation, since approximately 20% of the costs are attributable to smaller components (cf. interview ref.: B10: 64). As a result, BIM models in preliminary design often exhibit a level of development comparable to that of design development. Moreover, the information provided in early project phases may be insufficient for model-based cost estimation.

Although tenders for unit-price contracts are generally prepared on the basis of detailed design or execution planning, some infrastructure projects are already tendered on the basis of design development. Consequently, execution planning is transferred to the contractor, while the bill of quantities as the contractual basis becomes decoupled from the execution model and from BIM-based cost accounting.

Existing BIM-capable software systems have primarily been developed for building construction, which facilitates their implementation among different project stakeholders in this domain. By contrast, infrastructure construction faces specific technical challenges, such as the modelling of complex geometries or the absence of specific component classes in the IFC schema. These issues were addressed with the introduction of IFC 4.3 in 2024 as part of the ISO 16739 standard [41].

Most infrastructure projects are initiated by public clients. On the one hand, public clients define the project rules and can therefore establish favourable conditions for the implementation of the 5D BIM methodology. On the other hand, several processes that are not yet BIM-compliant must first be redesigned in order to enable a BIM-compliant way of working.

V. DISCUSSION

Realization of the Benefits of the 5D BIM System

The successful implementation of the 5D BIM information system is not aimed only at generating isolated benefits within individual project phases, but at establishing purposeful, continuous, and managed information flows in the context of cost management. This requires the active involvement of all project participants. The case study shows that, under certain conditions, closed BIM approaches offer advantages over open BIM when transferring information into cost planning. A focus on company-internal benefits in the use of 5D BIM does not necessarily contradict benefits at the overall project level. Even in early project phases, smaller-scale benefits should be realized in order to support downstream processes. The basis for scalable added value lies in uniform standards for the loss-free exchange of semantic building data and in the cross-phase linking of relevant cost information.

Paradox of the 5D BIM System

The paradox in the application of the 5D BIM information system lies in the fact that information losses in current cost management remain unchanged despite the use of the BIM methodology, just as in conventional cost management. Although selective improvements in cost management can be observed, overall, the BIM methodology has further complicated the cost management process within the project. Figure 4 contrasts the increase in information in conventional project development, the intended increase in information in a project developed using the BIM methodology, and the information discontinuities in the actual process of BIM-based cost management.

The information breakpoints (not to scale) indicate a flawed integration of the BIM methodology into the existing cost management process. Although several studies proposed 5D BIM workflows, these BIM-based methods largely preserve traditional cost-management practices rather than transforming them [7, 18, 42]. For example, billing, tendering, and cost tracking are frequently executed using conventional documentation rather than being driven directly by BIM models. Information discontinuities and the lack of data reuse in cost management therefore persist throughout the project life cycle, mirroring conventional practice [14].

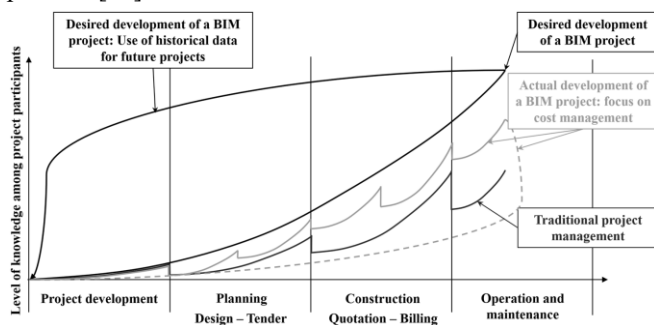


Fig. 4. Paradox of the Application of the 5D BIM System.

One essential aspect of BIM, namely, the continuity and interlinking of information, is currently not being realized across project phases in cost management. If the existing breakpoints in BIM-based cost management are institutionalized as intended breakpoints in the digital process chain, as proposed in [43], the potential of the 5D BIM information system cannot be fully exploited.

Contribution and Implications

The findings have direct implications for the further development and support of BIM-based industrial solutions for cost management, as well as for the broader integration of digital technologies into cost management processes. Previous research has already identified the lack of continuous cost control from design to construction as a persistent challenge and has attributed this problem to issues such as interoperability gaps, limited integration with cost databases, and the absence of real-time cost feedback [44]. However, this study provides a more differentiated explanation of these challenges.

The study indicates that technical interoperability is not the main barrier. Technical challenges related to data exchange, software interfaces, and standardized exchange formats can largely be addressed by software vendors, particularly as relevant standards have already been implemented to a considerable extent. Instead, the central challenge lies in semantic interoperability, as defined in the European Interoperability Framework [48]. Cost-relevant information is defined, structured, and interpreted differently across project phases and by different stakeholders. As a result, the same BIM-based information system may support technical data exchange while still failing to provide a consistent basis for cost estimation, cost control, and cost management throughout the project lifecycle.

5D BIM does not solve the problem of lacking experience. Experience and domain knowledge remain as important in 5D BIM processes as they are in traditional cost management processes. Moreover, compared with conventional workflows, 5D BIM requires additional technical skills that must be developed and integrated into everyday project practice.

Design-to-cost workflows based on BIM models have been described in several studies [10, 14, 18, 22, 23]. While these approaches represent an important achievement, reliable knowledge about construction costs is often required earlier than a comprehensive BIM-based cost model can be produced. Therefore, 2D-based information remains necessary for cost estimation, particularly in infrastructure projects, where modelling in early project stages is limited by the available data, information, and knowledge. In this context, the 5D BIM concept should be understood as a link between quantities and cost elements of the construction process, integrating both 2D-based and BIM-based data.

Furthermore, BIM models alone are insufficient to capture all information relevant to cost management. Therefore, typical 5D BIM workflows rely on linking BIM models with external data sources in order to ensure continuity across cost estimation, cost control, and cost management processes. Since these links cannot always be established unambiguously or at the required level of granularity, an ontology-based representation of cost-related knowledge provides a promising means of supporting semantic interoperability [34]. This is particularly relevant because resources and construction processes, which form a central

basis for cost formation, cannot be represented directly within the BIM model. This challenge becomes even more pronounced when considering emerging construction methods, such as 3D printing, where established cost structures and process-related dependencies may differ substantially from conventional construction methods [47].

Limitations of the Study

To position this study within the broader scientific context and to support the appropriate interpretation and use of its findings in future research, several limitations must be acknowledged.

First, the qualitative design and sample size support analytical rather than statistical generalisation. The findings should therefore be understood as an analytical generalisation of context-bound patterns observed within the investigated project and stakeholder settings. Their transferability should be assessed based on the similarity of the respective organisational, contractual, and technological conditions.

Second, the composition of the sampling frame represents a potential validity limitation. All interviewees belonged to established BIM working groups and had prior 5D BIM experience. The study therefore mainly captures willing but struggling users, while sceptics, non-adopters, and firms that discontinued 5D BIM are not represented. Barriers such as unclear return on investment, limited organisational readiness, or skills shortages may consequently be underrepresented [49], whereas semantic interoperability challenges may appear more prominent. The findings should therefore not be regarded as a complete diagnosis of all adoption barriers.

Third, the findings may be affected by temporal effects. The empirical data were collected in 2022 and 2023. Since software functionalities, interoperability solutions, and data standards continue to evolve, some technical assessments may no longer fully reflect current conditions and should be revisited in future longitudinal or replication studies.

VI. CONCLUSION

This research contribution provides exploratory insights into 5D BIM practice in selected German companies. The qualitative, exploratory-descriptive approach aims at a high level of detailed understanding of the practices examined.

The findings indicate that technological advances in 5D BIM information systems coexist with persistent discontinuities in the underlying processes. Consequently, information discontinuities and the limited reuse of BIM-based cost data remain present throughout the project life cycle, closely reflecting conventional practice. The analysis further suggests that semantic interoperability [48], rather than technical interoperability alone, is a key factor explaining the gap between the benefits promised in isolated experimental settings and the practical implementation of 5D BIM as an information system across the project life cycle.

Based on detailed case observations, the study documents implementation realities and barriers in greater depth, thereby establishing a foundation for the more detailed investigation of individual sub-aspects in future research. This paper complements and extends the literature review on practical experiences with the 5D BIM methodology previously published at ECPPM [2], as well as the Europe-wide survey on the perceived benefits of 5D BIM for construction cost management recently published at EC3

[49]. In contrast to the implementation paradox case study published in a German national professional journal [14], the novelty of this paper lies in its cross-role contingency analysis within a multi-stakeholder project context, its concise comparison of building construction and infrastructure projects, and its explicit focus on diagnosing semantic interoperability issues.

The practical implications of this study can be summarised as actor-specific recommendations. First, software vendors should address technical deficiencies, particularly information loss during data exchange between software systems, to strengthen collaboration in construction cost management and support the wider adoption of Open BIM workflows. They should also prioritise the further development of software functionalities that enable semantic alignment and improve interoperability between heterogeneous systems.

Second, public clients should place greater emphasis on defining structured, consistent, and uniform information requirements. A higher degree of standardisation is essential for preparing BIM models for cost planning and cost estimation processes. In particular, compatibility between the attribute requirements of clients and contractors can significantly simplify internal company processes supported by 5D BIM.

Third, small and medium-sized enterprises (SMEs) should adopt a realistic minimum viable configuration of their 5D BIM systems. Rather than implementing overly complex solutions from the outset, SMEs should focus on a limited set of clearly defined use cases, compatible software components, and manageable information requirements that reflect their organisational capacities and project needs.

Moreover, the findings serve as a starting point for the design of downstream solution approaches. By synchronizing the identified variables related to information quality, system quality, and service quality (IQ, SQ, SeQ), viable applications for companies and the wider industry can be derived and further developed.

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