CONCEPT DEVELOPMENT FOR ADOPTING 5D BIM IN SMALL AND MEDIUM-SIZED ENTERPRISES OF THE AEC INDUSTRY

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ABSTRACT

In order to achieve multiple benefits of building information modelling (BIM) in the construction project, the BIM methodology should not only be implemented in a project-related manner but also in a fully enterprise-related manner. Thereby model-based costing is one of the most important BIM use cases, which can be found in any project stage and is relevant to all project stakeholders. But the small and medium-sized enterprises (SMEs) of the architecture, engineering, and construction (AEC) industry in the particular face numerous problems and difficulties in adopting the BIM methodology in their business processes. This research aims to investigate the process of the 5D BIM implementation in small and medium-sized planning, engineering offices, construction companies, and project developers. The main body of the work is based on a review of 24 implementation projects of the model-based costing in SMEs that the authors have carried out as part of their practice as BIM consultants and trainers in Germany. These projects are analysed to develop a concept for a smooth, individually adaptable implementation of 5D BIM in SMEs. The results are summarised in the concept framework for a sustainable 5D BIM implementation approach that illustrate the priority and hierarchy of the main activities in the implementation process. The designed concept can be used by different stakeholders of the AEC industry and provides a solid basis for organisations to make informed decisions in adopting 5D BIM in the body of the organisation structure. Thus, this research is an essential contribution to the knowledge about the enterprise-related implementation of 5D BIM.

Keywords: 5D BIM methodology, BIM implementation, adoption, small and medium-sized enterprises (SMEs), organisation, quantity take-off, cost estimation, cost calculation, concept framework.

1 INTRODUCTION

In the wake of the emergence of the coronavirus pandemic at the beginning of 2020, several construction companies started to invest more in digital resources. In this context, the BIM methodology represents an important part of the digitalisation of the construction industry. In the German AEC industry, e.g., one-third of all building companies are currently planning to align their business model more strongly than before with digital services and to expand the digitalisation of their business processes [1]. In 2017, in contrast, only 9.6% of German construction companies used BIM methods to manage construction projects [2].

BIM methodology is not spreading rapidly in the AEC sector because many construction companies still think of BIM implementation as just a simple exchange of tools and therefore find it difficult [3]. Although, a fundamental part of the BIM methodology is to address the processes by using and sharing digital building information. BIM aims to transfer project-relevant information as comprehensively and completely as possible [4]. In this case, digital tools can only bring added value and be accepted by the AEC actors if the processes are clearly defined. Technical tools must help to create a collaborative, usable, digital representation of a physical object and its functional characteristics [5].

The linking of the digital representation of the building elements with time and cost data forms one of the significant BIM use cases. Model-based scheduling and cost estimation are classified as the 4D and 5D BIM dimensions [6]. The article focuses primarily on model-based cost planning and related activities, regardless of whether model-based scheduling is

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performed. According to Eastman 5D BIM intends to link cost items with specific, measurable features of the model object, so that project costs can be forecasted and actual costs can be tracked about the BIM model [7]. Therefore, model-based cost estimation depends significantly on the quality of the model data, information deliveries and is linked to the other BIM use cases, such as design and execution planning. 5D BIM itself can be subdivided into several specific use cases, such as cost estimation in the early project phases, calculation of construction work for contractors, budgeting for project developers, etc.

As cost planning is a fundamental activity in the AEC industry, 5D BIM is relevant for all project phases as well as for all project participants. One of the most crucial benefits of the BIM methodology, cost assurance in construction projects, can be realized by the 5D BIM application. If to use the advantages of the BIM methodology and especially 5D BIM for the safe cost in multiple projects, BIM is to be implemented both in the project and in the company. The project-based implementation in the context of a pilot project or case study is only a part of the enterprise-related digital transformation.

The implementation of BIM depends on various influencing factors, e.g., organisation culture, education, information management [8]. For adopting BIM, construction project participants usually have to define BIM goals and use cases, develop a process road map, design a BIM execution plan (BEP), and chose a technical infrastructure, as well as clarify a lot of strategic, operational, tactical, and technical questions [9]. In most cases, SMEs are overwhelmed with all these additional tasks, the required implementation steps, and volumes of incoming information. However, SMEs often do not dispose of the financial resources to get any external support into the company. For this reason, SMEs are still lacking in the implementation of BIM. In the European Union, SMEs are a significant part of the economy, and account for approximately 22.6 million in 2021 [10]. Thereby 99.8% of all European companies are SMEs, which act as the main drivers of innovation and digitalisation [11]. In the German AEC industry, e.g., more than 93% of planning and engineering offices employed fewer than 50 professionals [12]. Hence, the comprehensive implementation of the BIM methodology in the AEC sector depends on BIM adoption in SMEs.

The focus of this research is, therefore, on developing the concept for better 5D BIM adoption and implementation in the SMEs of the AEC sector. The impulse for this scientific work is the professional experience of the authors as BIM trainer and consultant primarily for the issues of 5D BIM implementation in different companies, such as planning, engineering offices, construction companies, and project developers.

2 METHODOLOGY

The research provides a synthesis of the reviewing of scientific papers and the analysis of the authors' practical expertise and attempts to bridge a gap between theoretical fundamentals and practical implementation of the 5D BIM methodology. The literature review is a qualitative review of scientific papers in the research areas of BIM implementation, cost planning in the AEC projects, and management theories. The most relevant terms for the literature survey can be divided into three groups, which have been combined among each other: (1) BIM, implementation, adoption; (2) 5D BIM, costing, cost estimation, cost estimate, cost calculation, cost control; (3) SMEs, organisational, enterprise, construction company, contractor. It has been noticed that the research papers addressed often change management in the context of the company-related implementation of the BIM methodology. Hence, innovation management and business process change management are briefly explained.

To assess the practical applications of the theoretical findings, 24 implementation projects of the model-based costing of 5D Institut GmbH in Germany have been investigated. The

article provides a qualitative review of the 5D BIM implementation projects, summary, and analysis of the preliminary project meetings, includes die results of not structured interviews with participants. The meaningful features and issues encountered are highlighted.

Due to professional confidentiality, the executed implementation projects cannot be mentioned by name. A distinction is made between the implementation packages for planners and clients as well as for construction companies and contractors. The authors are also limited in their choice of the model-based costing software and work exclusively with RIB iTWO 5D. However, the preliminary BIM model can be created in any BIM-capable software that is certified for IFC export. A BIM implementation project starts when the decision about the IT infrastructure has been made, and a technical realisation of the BIM goals must be carried out. Nevertheless, the authors often have to consult the clients on the entire BIM implementation plans and refine the BIM use cases. The general procedure of a standard consulting project for clients and contractors is shown in Fig. 1.

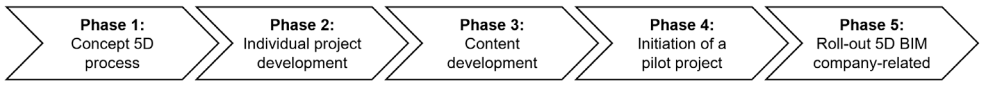


Figure 1: The general procedure of a consulting project by 5D Institut GmbH.

3 LITERATURE REVIEW

To provide a solid basis for organisations to make informed decisions in adopting 5D BIM in the body of the organisation structure, the general steps for the BIM implementation should be considered in the context of the enterprise-specific cost calculation processes. Model-based cost planning and control could be used by different AEC stakeholders, e.g., government, owner, designers, contractors, operation organisations, cost engineers, and during various project stages, e.g., in the conceptual, design, procurement, construction, completion stages. Therefore, different approaches and tasks can arise during implementation. The principal 5D BIM use cases will remain under any circumstance quantity take-off and cost estimation.

3.1 Implementation of the BIM methodology

The application of the BIM methodology can be considered on different levels, such as implementation in the whole AEC industry [13], country-related adoption [14]–[17], development in a single firm [18], [19], and project-based implementation [20], [21]. Some authors emphasise that large construction companies operating on a design-and-build basis have already adopted BIM [22]. These contractors can usually manage their entire internal processes independently of other construction stakeholders, thus giving them an advantage over SMEs. As clients require BIM services more consistently, SMEs should advance the internal digitalisation process to remain competitive in the market.

Therefore, the guidelines for BIM implementation at the operational level are needed. They can include aspects such as the BIM adoption scope, discipline, model analysis and data transfer methods, interoperability, and staff responsibilities [13]. Feasible results with BIM in SMEs can be obtained if the internal BIM model structure, standard information linked to model objects, critical information workflows as well as collaboration with external stakeholders are defined [3], [23]. Company-related BEP and standards must elaborate on issues like “scope of implementation, infrastructure, contracts, implementation process” [24].

At the same time, BEP for enterprise-related implementation should prioritise the program–process–person perspective [25].

3.1.1 Factors influencing BIM implementation

According to the BIM implementation level examined, the critical success factors may be different. For BIM adoption in the national AEC industry, e.g., the factors like development standards, acceptance by professionals, educational offers, or pilot projects [6] are significant. For BIM implementation in construction projects highlight Darwish et al. fifteen factors as the most critical ones [21]. The first factors influencing BIM implementation are coordination between all project parties as well as training and development. Collaboration between AEC stakeholders, availability of competencies and experiences, BIM adoption strategy influence the BIM implementation in a project-related manner [21]. According to the research by Arayici et al., construction stakeholders, who have been implementing BIM, emphasise the importance of staff training on new processes as well as on new software and technology, effectiveness and establishment of the new process and workflow, understanding of BIM, a realization of competitive advantages, purchase of software and technology [8].

3.1.2 Challenges of BIM implementation

The main obstacles to BIM adoption may be divided into four large general groups, e.g., mentality, knowledge and skill, software, and hardware [3], or categorized into five limitation categories, such as technological, legal, personnel, cost, and management barriers [26]. However, scientific research papers on the hindrances to BIM adoption are primarily related to a specific country. The main barriers for the Chinese AEC industry formulated by Wu et al. [15] are senior management support and financial investments. New Zealand struggles with such challenges as lack of expertise, client demand, and collaboration, shortage of pilot projects and guidelines, cultural resistance, legal and technical problems [17]. In Iraq, the implementation barriers are divided into legal, organisational, and technological [16]. In comparison, the construction industry in Latin America is faced with change resistance, bureaucracy, lack of regulations, human resources, and administrative initiative, etc. [18]. Especially for SMEs, six challenges are formulated in previous research: limited resources, collaboration, lack of BIM knowledge, legal disputes, unsteadiness in regulations, adherence to the advantages of SMEs, data protection, and responsibility for the information [27].

3.2 Cost planning in the AEC projects

Cost planning and control are basic tasks in AEC projects. While planning is primarily concerned with realistic cost determination, cost control is of great importance during execution. According to the planning status, there are different levels of information in the cost calculation. In the German AEC industry, e.g., architects, planners, and project developers usually use the DIN 276 (German Institute for Standardisation e.V.) standard to determine project costs [28], [29]. Construction companies that take over the execution services must consider the following partial costs in their cost estimation: (1) material costs; (2) labour costs; (3) expenses of the construction tools; (4) indirect costs [30]. The costing of the construction company encompasses the following phases: pre-calculation (subdivided into quotation costing, contract costing, work execution estimate) and post-calculation [30].

Regardless of the project phase and construction participants, the quantity take-off is a foundation for the cost estimation. In the concept project phase quantity estimation provides the base for budget planning. In the tendering phase it supports the estimation of the project costs and the first statement on the execution time. Before the execution phase, it facilitates

the calculation of the construction works and planning of construction activities. During the construction phase, actual quantity take-off is used for cost control [31]. The accuracy and level of granularity of quantity surveying vary throughout the project.

3.2.1 Traditional cost estimation

Some challenges in traditional cost estimation impact the project cost: problems with sharing information and lack of communication as well as collaboration between different project stakeholders, e.g., design and construction teams, regarding cost activities [32]. The total expenses of a project are often unknown until after the conceptual design stage, and in some circumstances, even after finishing the construction stage [33], [34].

The quantity survey is therefore error-prone in the conventional calculation method and requires an investment of time. Manual calculation on CAD documents, that only store limited information, is a basement of the traditional quantity take-off. This approach not only requires a high level of human resources but also causes deviations quite easily [35].

3.2.2 5D BIM methodology

During BIM-based cost planning, the so-called design-to-cost method is applied. The accuracy of cost planning, i.e., the progress from a cost estimate to a cost calculation, is largely dependent on the project development. With the advancing project phase, more information is added to the model. This results in a continuous refinement process, which leads to a final cost calculation. In the early stages of planning, a cost estimate is prepared using the *deductive costing* methodology, which operates *top-down*. This means that a general budget is derived based on real costs from past projects, considering decisive factors such as the construction method. Such an approach utilises cost elements [28] and is comparable to cost estimation with the help of the construction cost index [36]. Later, more detailed cost calculations are carried out *inductively* and thus *bottom-up*. The individual costs of the components are multiplied by the expected quantity to be executed. Unit prices are determined based on a price database. Quantity formulas are used to perform a component-based quantity take-off founded on the model property records.

To be able to guarantee cost safety within a project, cost planning must keep pace with the constantly progressing project planning. Model-based quantity take-off is the only method that makes progressive cost planning possible. However, model-supported quantity estimation does not produce all the required data to create a cost estimation and bill of quantities [31]. Model-based cost estimation combines quantities gained from models and additional information such as cost elements, unit prices, construction price index, specification of services, and other cost-related information. Moreover, the geometrical information of the BIM model must be transferred into geometrical information that conforms to the estimation procedure [37]. Additionally, from the perspective of a construction company, the model-based quantities are translated into quantities of materials, equipment, manpower, etc., and afterwards into costs [38].

In the scientific literature, are some frameworks for 5D BIM process integration that encompass the whole cost management process [39], focus on the tendering phase [40], try to facilitate costing in contractor-led projects [33], present general workflows of 5D BIM process by different stakeholders [7], provide guidance in BIM implementation for construction companies [24]. However, the research papers notice that it is challenging to overcome the 5D BIM implementation obstacles, e.g., the lack of a framework for information exchange and compatibility between software applications, cost data sharing, and poor model data quality [31], [33].

3.3 Management theories

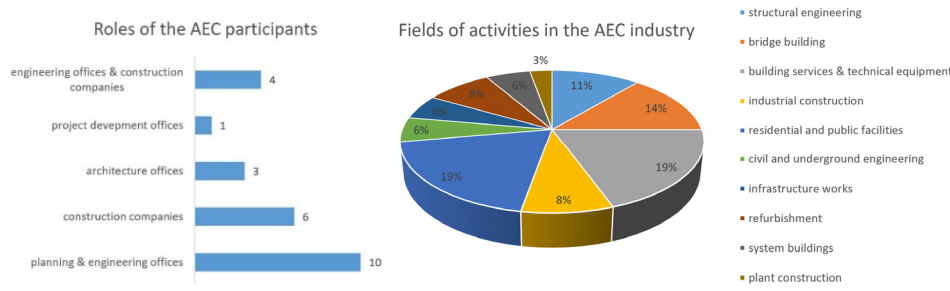
BIM methodology brings the changes into the business process of the construction sector, which can be conducted on two levels: sector-wide and individual organisations [41]. Thereby, a simply methodical implementation of BIM does not cover all organisational areas and does not sufficiently lead the individual actors into the change. BIM adoption requires an entrepreneurial vision, which is developed and communicated by the executive staff. Consequently, strategy, structure, and management processes are essential aspects of BIM implementation, in addition to technology, individual skills and roles. BIM methodology concerns the management of information, such as information on building products, materials, structures, customer requirements, information on technical equipment, general requirements for planned installations, etc. Communication and collaboration between stakeholders are defined as keys to accomplishing smooth information management [24].

BIM is suggested as social-environmental, technological, organisational, and process–product innovation in the AEC industry [19]. This digital innovation requires changes in individual roles, needs time, appeals resources, acquisition of knowledge, financial investment, etc. For a successful implementation of the BIM methodology, the organisational change is required. Organisational change process needs a development strategy, the involvement and engagement of all stakeholders as well as management support [20]. The role of the manager is frequently placed very high, as one of the most important obstacles must be overcome, namely resistance to change. In this context, it is significant that the entire benefit of the BIM methodology for the enterprise is explained to each participant. According to Weise [42], change management with its variables (organisation and process orientation, resources, technology, strategy, culture, individual) plays a decisive role in the enterprise-related BIM adoption.

4 INVESTIGATION OF IMPLEMENTATION PROJECTS

5D BIM implementation projects selected for the investigation were carried out by different AEC stakeholders: architecture, planning, and engineering offices, construction companies, project development offices. The design and construction activities of parties involved in the study are multifaceted. The chosen companies are engaged in structural engineering, design and construction of industrial buildings, plant construction, bridge building, construction of residential and public facilities, infrastructure works, civil and underground engineering, refurbishment, building services and technical equipment, building automation as well as system buildings and finishing works. Among executing construction companies, there are some large companies that initially want to adopt 5D BIM in one department for the time being. As a local office does not exceed the size of an SME, it can be taken into consideration. 24 company-related implementation projects are summarised according to the roles of stakeholders and fields of activities in Fig. 2.

The 5D BIM implementation projects have the following limitations: (1) in some projects, only Phase 1 Concept 5D process (see Section 2, Fig. 1) was contracted, therefore the further development could not be evaluated; (2) some planning offices need much time to adopt 3D modelling and master the modelling tools for the design planning because of staff shortage before moving to 5D BIM; (3) 5D BIM implementation depends on the contracts with the client. As all projects are carried out in Germany, the Official Scale of Fees for Services by Architects and Engineers [29] and special features of cost planning (see Section 3.2) had to be observed. The most common BIM use cases are cost estimation in the design and tendering phases for planning offices, as well as quotation costing for construction companies.



(a) (b)

Figure 2: Implementation projects. (a) Roles of the participants; and (b) Fields of activities.

The analysis of the 5D BIM adoption has shown that

- Communication within a company must be seriously reconsidered with the implementation of the BIM methodology. BIM model authors and estimators sometimes have heard each other's problems for the first time during the workshop.
- The size of the company has less influence on the adoption of the BIM methodology. The larger companies have more employees involved, but the same problems.
- If there was no responsible person for the enterprise-related BIM implementation, the digital transformation in the company would drift off.
- Clients' demand for BIM services is important for most participants.
- 5D BIM implementation is an iterative process [3] demanding constant harmonization between BIM model creation and refinement of the costing database. LOD of a designed model should be sufficient to provide accurate quantities.
- Many participants still see BIM only as a tool and not as a methodology and therefore see no need to change their old processes.
- Software selection often happens before the BIM use cases are clearly defined.
- There was no BIM implementation plan as well as a clear strategy in most projects.
- Many participants saw the implementation of the BIM methodology as a management decision but not as an advantage for their work practices.
- The companies were not interested in a model-based exchange with external parties.
- In the preliminary discussions it had to be explained that a feasible enterprise-related system for model-based cost planning could not be built in five days of workshop.
- Fields of activities influence the level of automation for model-based cost planning. For instance, more quantity take-offs can be automatically extracted from BIM model in building construction than in industrial construction. In the cost planning for the modular buildings allows almost the entire process to be automated.
- Construction companies without a modelling department are struggling to implement 5D BIM, while the model data from external architecture, planning, or engineering offices have not met their requirements.
- The previous estimating database is incorrect or out of data must be completely revised before making the switch to 5D BIM [43].
- Companies should plan more time for the adopting and restructuring of processes.
- Interoperability between the software applications is the major topic for the technological implementing and must be discussed in the planning of IT landscape.

- Different project participants have different views on cost estimation and, accordingly, on quantity take-off from the BIM model.
- National peculiarities, such as strong fragmentation of the German AEC sector and use of HOAI, complicate the implementation process. Due to the BIM methodology, a shift in the service phases is also observed in German offices.

5 RESULTS AND DISCUSSIONS

The following requirements for the development of a sustainable implementation concept are defined based on the literature review and investigation of practical implementation projects.

1. Concept must cover management, process, and technology issues [44], namely address strategic, operational, tactical, and technical questions [9].
2. Survey of current situation of BIM in an organisation, as well as effective external factors influencing BIM implementation, belongs to the preliminary adopting stage.
3. Establishing BIM is part of the company's strategic tasks. Therefore, a responsible BIM manager must be appointed in the company at the very beginning.
4. BIM should be regarded as a corporate standard that includes developing the company-related guidelines and BIM execution plan for projects.
5. Clear identification of BIM benefits, goals, and use cases for the company.
6. BIM implementation plan is not only "nice to have", it is to be created for a company.
7. All employees must be involved in the digital transformation.
8. Collaborative work in changing old processes and workflows.
9. BIM education and training: general in the first adopting stage and later role-specific.
10. Sequence of decisions: first strategy, then software selection.
11. Development of 5D BIM model content and information workflows as iterative approach, permanent coordination between the BIM model authors and estimators.
12. Selection of a pilot project and, if necessary, coordination with the client.

The concept for a smooth implementation of 5D BIM designed is presented in Fig. 3. To show the order and hierarchy of the main activities, the concept framework was created without assigning the roles. Depending on whether this model concept is realised for architecture, planning, and engineering offices or construction companies, the roles and responsibilities are respected regarding organisation size, internal and external relationship between the stakeholders. The information exchange must surely happen in the implementation phase and afterwards among BIM manager, BIM model authors, and estimators. BIM education and training is essential for the BIM adoption process.

6 CONCLUSION AND FUTURE RESEARCH

The developed concept provides a fundamental framework for AEC enterprises to make informed decisions in adopting 5D BIM in the body of the organisation structure. This concept framework should prepare a smooth, individually adaptable implementation by different stakeholders of the AEC industry. Hence, this article presents a significant part of knowledge about the 5D BIM implementation in the enterprise-manner. The research tries to overcome the most important limitations during 5D BIM adopting, as lack of skills and resistance to change, and represents a comprehensive approach. In comparison with other scientific papers [38], [40], [44], [45], this article encompasses the BIM implementation strategies and 5D BIM adoption methods as well as points the view of the external observer on the issue.

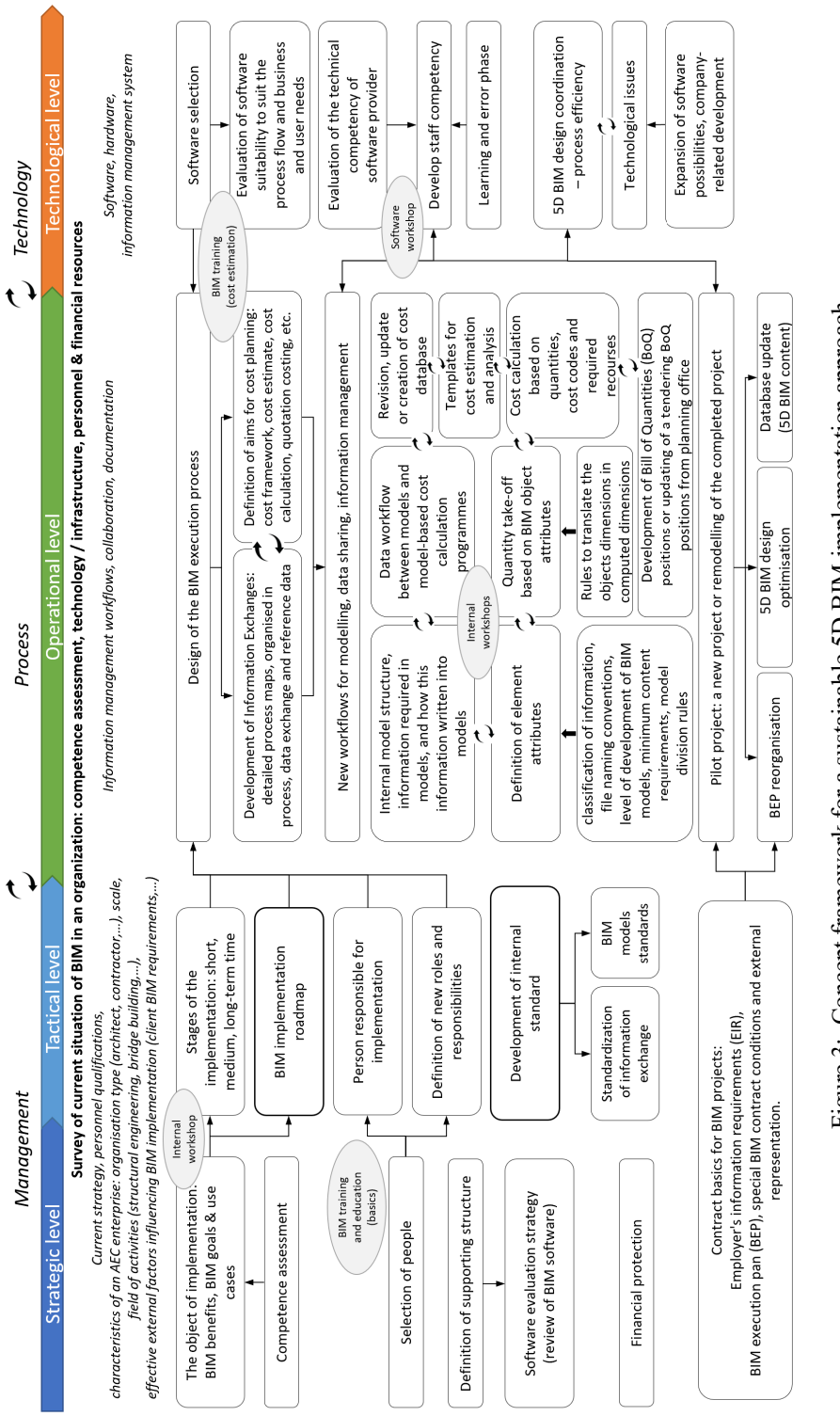


Figure 3: Concept framework for a sustainable 5D BIM implementation approach.

The future research can deal with the development of information exchanges for 5D BIM on the operational level such as requirements for detailed process maps. Although the implementation projects from the practical part of the research were carried out in Germany, results can be adopted internationally. In the forthcoming research, more attention should be paid to the national particularities and the more detailed procedures should be designed separately for planning offices and construction companies.

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REFERENCES

[1] Deutsche Telekom, A.G. (eds), Der digitale Status quo im deutschen Baugewerbe, p. 14. https://www.digitalisierungsindex.de/wp-content/uploads/2021/01/Telekom_Digitalisierungsindex_2020_BRANCHENBERICHT_BAUGEWERBE.pdf. Accessed on: 1 Sep. 2020.

[2] PricewaterhouseCoopers (eds), Digitalisierung der Bauindustrie 2020. PwC-Studie zur Digitalisierung der Baubranche unter Berücksichtigung der Corona-Pandemie und des Infrastrukturausbau, p. 19. https://www.pwc.de/de/digitale-transformation/pwc-studie-digitalisierung-der-bauindustrie-2020.pdf. Accessed on: 1 Sep. 2020.

[3] Cesnik, J., Zibert, M., Lah, M. & Matic S., Required model content and information workflows enabling proficient BIM usage. *Proceedings of the IOP Conference Series: Materials Science and Engineering*, **603**, 032074, 2019. DOI: 10.1088/1757-899X/603/3/032074.

[4] Egger, M., Hausknecht, K., Liebich, T. & Przybylo, J., *BIM-Leitfaden für Deutschland*, Bundesministerium für Verkehr, Bau und Stadtentwicklung: Berlin, p. 18, 2013.

[5] Daniotti, B., Gianinetto, M. & Della Torre, S. (eds), *Digital Transformation of the Design, Construction and Management Processes of the Built Environment. Research for Development*, Springer: Cham, p. 103, 2020.

[6] Borrmann, A., König, M., Koch, C. & Beetz, J. (eds), *Building Information Modeling - Technologische Grundlagen und industrielle Praxis*, ed. J. Beetz, Springer Vieweg: Wiesbaden, 2015.

[7] Eastman, C.M., Teicholz, P., Sacks, R. & Liston, K., *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Architects, Engineers, Contractors, and Fabricators*, John Wiley and Sons: Hoboken, NJ, 2011.

[8] Marshall-Ponting, A., Arayici, Y., Khosrowshahi, F. & Mihindu, S., Towards implementation of building information modelling in the construction industry. *Proceedings of 5th International Conference on Construction in the 21st Century (CITC-V)*. Istanbul, Turkey, May 20–22, 2009. DOI:10.13140/2.1.3776.6080.

[9] Baldwin, M., *Der BIM-Manager: praktische Anleitung für das BIM-Projektmanagement*, Beuth Verlag GmbH: Berlin, Wien, Zürich, pp. 112–137, 2018.

[10] Number of small and medium-sized enterprises (SMEs) in the European Union (EU27) from 2008 to 2021, by size. https://www.statista.com/statistics/878412/number-of-smes-in-europe-by-size/. Accessed on: 1 Sep. 2020.

[11] Policy Learning Platform SME Competitiveness (eds), Policy Brief, The SME policy of the European Union, p. 1. https://www.interregeurope.eu/fileadmin/user_upload/plp_uploads/policy_briefs/TO3_policy_brief_2__SME_policy_final_V23_01_2017_Siriuss_LS_clean.pdf. Accessed on: 1 Sep. 2020.

[12] Institut für freie Berufe Nürnberg (IFB) (eds), Umfrage zur Lage der Ingenieure und Architekten im Auftrag des AHO, der Bundesingenieurkammer, des VBI und des BDB – Index 2014, wirtschaftliche Strukturdaten, pp. 18–19, 2015.
[13] German Institute for Standardisation (DIN) (eds), *VDI-Richtlinie 2552-1, BIM-Grundlagen*, Beuth publishing DIN, p. 8, 2021.
[14] Wu, P., Jin, R., Xu, Y., Lin, F., Dong, Y. & Pan, Z., The analysis of barriers to BIM implementation for industrialized building construction: A China study. *Journal of Civil Engineering and Management*, **27**(1), pp. 1–13. DOI: 10.3846/jcem.2021.14105.
[15] Shibani, A., Awwad, A.K., Ghostin, M., Siddiqui, K. & Farji, O., Adopting building information modelling in small and medium enterprises of Iraq's construction industry. *Proceedings of the International Conference on Industrial Engineering and Operations Management*, Dubai, UAE, pp. 457–470, 2020.
[16] Doan, D.T., GhaffarianHoseini, A., Naismith, N., Ghaffarianhoseini, A., Zhang, T. & Tookey, J., Examining critical perspectives on building information modelling (BIM) adoption in New Zealand. *Smart and Sustainable Built Environment,* 2020. DOI: 10.1108/SASBE-04-2020-0043.
[17] Pinilla, C.A.V. & Riaño, L.N.A., Architectural model of implementation of building information modeling – BIM in the Colombian Construction Industry. *Proceedings of the International Conference on Industrial Engineering and Operations Management*, Toronto, Canada, pp. 142–152, 2019.
[18] Arayici, Y., Coates, S., Koskela, L.J., Kagioglou, M., Usher, C. & O'Reilly, K., BIM adoption and implementation for architectural practices. *Structural Survey*, **29**(1), pp. 7–25. DOI: 10.1108/02630801111118377.
[19] Villena, F., García-Segura, T. & Pellicer, E., Drivers of innovation using BIM in architecture, engineering, and construction firms. *Proceedings of the Construction Research Congress,* 2020. DOI: 10.1061/9780784482889.023.
[20] Bråthen, K. & Moum, A., Involvement matters: BIM implementation at project level in the AEC industry. *WIT Transactions on the Built Environment,* vol. 149, WIT Press: Southampton and Boston, pp. 157–168, 2015. DOI: 10.2495/BIM150141.
[21] Darwish, A.M., Tantawy, M.M. & Elbeltagi, E., Critical success factors for BIM implementation in construction projects. *Saudi Journal of Civil Engineering,* **4**(9), pp. 180–191, 2020. DOI: 10.36348/sjce.2020.**4**i09.006.
[22] Davies, R. et al., BIM in Europe: Innovation networks in the construction sectors of Sweden, France and the UK. *Proceedings of the 31st Annual ARCOM Conference*, eds A. Raiden, & E. Aboagye-Nimo, pp. 1135–1144, 2015.
[23] Abuelmaatti, A. & Ahmed, V., Collaborative technologies for small and medium-sized architecture, engineering and construction enterprises: Implementation survey. *Journal of Information Technology in Construction (ITcon),* **19**, pp. 210–224, 2014.
[24] Gercek, B., Tokdemir, O.B., Ilal, M.E. & Gunaydin, H.M., BIM execution process of construction companies for building projects. *Resilient Structures and Sustainable Construction*, eds E. Pellicer, J.N. Adam, V. Yepes, A. Singh & S. Yazdani, ISEC Press, 2017.
[25] Hjelseth, E., BIM understanding and activities. *WIT Transactions on the Built Environment,* vol. 169, WIT Press: Southampton and Boston, pp. 3–14, 2017. DOI: 10.2495/BIM170011.
[26] Enshassi, M.A., Hallaq, K.A.A. & Tayeh, B.A., Limitation factors of building information modeling (BIM) implementation. *The Open Construction and Building Technology Journal,* **13**, pp. 189–196, 2019. DOI: 10.2174/1874836801913010189.

[27] Li, P., Zheng, S., Si, H. & Xu, K., Critical challenges for BIM adoption in small and medium-sized enterprises: Evidence from China. *Advances in Civil Engineering*, **2019**, 9482350, 2019. DOI: 10.1155/2019/9482350.
[28] German Institute for Standardisation e.V. (DIN) (eds), *DIN 276:2018-12, Kosten im Bauwesen*. Beuth Publishing DIN, 2018.
[29] HOAI, *Official Scale of Fees for Services by Architects and Engineers (in Germany)*. Duesseldorf: Werner Verlag, 2013.
[30] Bargstädt, H.-J. & Steinmetzger, R., Grundlagen des Baubetriebswesens. *Schriften der Professur Baubetrieb und Bauverfahren*, pp. 220–222, 2016.
[31] Monteiro, A. & Martins, J.P., A survey on modeling guidelines for quantity takeoff-oriented BIM-based design. *Automation in Construction,* **35**, pp. 238–253, 2013. DOI: 10.1016/j.autcon.2013.05.005.
[32] Huang, X., Application of BIM big data in construction engineering cost. *Journal of Physics: Conference Series*, **1865**(3), 32016, 2021. DOI: 10.1016/j.aei.2016.07.001.
[33] Moses, T.G., *The Development of 5D BIM Framework to Facilitate Costing in Contractor-Led Projects*, Post-doctoral qualification, University of Wolverhampton: Wolverhampton, 2018.
[34] Ashworth, A. & Perera, S., *Cost Studies of Buildings*, 6th ed., Routledge: Florence, pp. 121, 530, 2015.
[35] Rui, Y., Review of building information modeling (BIM) application in construction industry. *International Journal of Innovative Technology and Exploring Engineering,* **8**(6C2), pp. 83–87, 2019.
[36] BKI Handbuch Kostenplanung im Hochbau, Rudolf Müller, 2021.
[37] Ma, Z., Liu, Z. & Wei, Z., Formalized representation of specifications for construction cost estimation by using ontology. *Computer-aided Civil and Infrastructure Engineering*, **31**(1), pp. 4–17, 2015. DOI: 10.1111/mice.12175.
[38] Mirarchi, C., Trebbi, C., Lupica Spagnolo, S., Daniotti, B., Pavan, A. & Tripodi, D., BIM methodology and tools implementation for construction companies (GreenBIM Project). *Digital Transformation of the Design, Construction and Management Processes of the Built Environment. Research for Development*, eds B. Daniotti, M. Gianinetto & S. Della Torre, Springer: Cham, pp. 201–208, 2020. DOI: 10.1007/978-3-030-33570-0_18.
[39] Li, H., Yuan, Z., Han, J. & Li, Z., Whole process cost management system based on BIM 5D. *DEStech Transactions on Engineering and Technology Research*, ICAEN, 2019.
[40] Leicht, D., Castro-Fresno, D., Dìaz, J. & Baier, C., Multidimensional construction planning and Agile organized project execution—The 5D-PROMPT method. *Sustainability*, **12**(16), p. 6340, 2020. DOI: 10.3390/su12166340.
[41] Smith, D.K. & Tardif, M., *Building Information Modeling: A Strategic Implementation Guide for Architects, Engineers, Constructors, and Real Estate Asset Managers*, John Wiley & Sons Inc., 2009.
[42] Weise, F., Change management im Kontext des Building Information Modelings in Organisationen der Bauwirtschaft – Eine Analyse Erfolgskritischer Faktoren in BIM-Anwendungsfällen. *Kompetenzen für die digitale Transformation 2020*, eds L. Lehmann, D. Engelhardt & W. Wilke, Springer Vieweg: Berlin, Heidelberg. DOI: 10.1007/978-3-662-62866-9_5.

[43] Sattineni, A. & Macdonald, J.A., 5D BIM: A case study of an implementation strategy in the construction industry. *Proceedings of the 31st International Symposium on Automation and Robotics in Construction and Mining,* pp. 361–367, 2014. DOI: 10.22260/ISARC2014/0048.

[44] Moses, T., Heesom, D. & Oloke, D., Implementing 5D BIM on construction projects: Contractor perspectives from the UK construction sector. *Journal of Engineering, Design and Technology*, **18**(6), pp. 1867–1888. DOI: 10.1108/JEDT-01-2020-0007.

[45] Viscuso, S., Talamo, C., Zanelli, A. & Arlati, E., BIM management guidelines of the construction process for general contractors. *Digital Transformation of the Design, Construction and Management Processes of the Built Environment. Research for Development*, eds B. Daniotti, M. Gianinetto & S. Della Torre, Springer: Cham, pp. 189–199, 2020. DOI: 10.1007/978-3-030-33570-0_17.