CONFERENCE ON PRODUCTION SYSTEMS AND LOGISTICS
CPSL 2022

3rd Conference on Production Systems and Logistics

Adaption Of The Level Of Development To The Factory Layout Planning And Introduction Of A Quality Assurance Process

Thomas Neuhäuser[1,2], Lisa Lenz[3], Kai Weist[3], Andrea Hohmann[1], Rüdiger Daub[1,2]
[1]Fraunhofer Institute for Casting, Composite and Processing Technology
[2]Institute for Machine Tools and Industrial Management, Technical University of Munich
[3]Department of Construction Management, TU Dortmund University

Abstract

Current developments and trends are causing an increasingly turbulent environment for manufacturing companies. In order to respond to these dynamic market conditions, products and thus also production systems have to be adapted more frequently and much faster. However, time and cost targets are often missed by classic factory planning approaches due to poor communication, inadequate tools, and lack of interfaces. Therefore, new ways have to be found in factory planning to overcome these problems. Building Information Modeling, which is already used in the construction industry, provides a promising method for the collaboration of stakeholders based on digital models. This would allow communication to be structured, new tools to be used, and interfaces to be stabilized to improve the target achievement in factory planning projects. However, which information should be provided in which level of detail in which phase of a factory planning project and how the quality of this information can be ensured has not yet been answered. A possible solution to these questions is addressed in this article. First, the concept of the so-called Level of Development, i.e. the geometric and non-geometric definition of the model contents, is transferred to factory layout planning. Then, based on two use cases, the process of quality assurance is defined.

Keywords

Factory Planning; Building Information Modeling; Level of Development; Layout Planning

1. Introduction

The manufacturing industry is one of Germany's most important economic sectors, accounting for 23.5% of gross domestic product [1]. However, companies in this sector are facing trends such as globalization, dynamization of product life cycles and climate change as well as current challenges such as supply bottlenecks. These new circumstances force manufacturing companies to adapt and innovate. The focus is on new products, new processes, innovative supply networks and also the adaptation of existing or the creation of new factories. The adaptation cycles must be implemented faster and more frequently. Factory planning is thus becoming a continuous task for companies. [2–4]

The central target variables of planning projects are time, costs and quality. While the quality targets are generally achieved in factory planning projects, the time targets are missed in about 60% and the cost targets in approximately 72%. This is primarily due to four areas of potential improvement in the organization of factory planning projects: An improvement of communication and synchronization, a further development of instruments and tools used, an increase in planned agility in the course of the project, and an early detection of deviations [5]. The costs of errors on German construction sites amounted to 18.3 billion Euros in 2020 [6]. To solve these problems and leverage the potential for improvement, new approaches to factory planning must be found.

It is precisely this potential that the Building Information Modeling (BIM) methodology addresses. BIM is a collaborative working methodology based on digital models, called the Building Information Model. The Building Information Model is the primary instrument of the methodology, which is generated by tools such as authoring software. Those involved in the planning process regularly exchange the models in a systematic communication process, which are checked for deviations at an early stage and thus continuously synchronized. Agility corridors are planned into the project from the beginning in order to be able to eliminate any deviations and, if necessary, to draw several iteration loops. In addition, each project is built up modularly via project-specific goals and use cases [7–9]. Current studies show that the use of BIM in construction projects leads to a reduction in time in 34% and to a reduction in costs in 60% of the investigated cases [10].

While there are recommendations for the use of the BIM methodology in public and municipal construction as well as in infrastructure construction [8,9,11], the use of the methodology in factory planning is still largely unexplored [12,13]. To overcome these shortcomings, this paper presents a modeling guideline regarding the geometric and non-geometric level of detail in the factory planning process. Then, two BIM use cases to ensure modeling quality are presented and finally described as a process. Thereby, the focus is laid on the layout planning process, since in this phase the production system merges with the building to form the factory and a large part of the planning interaction between the individual trades takes place. The approach presented will be primarily geared towards German companies, as the *Honorarordnung für Architekten und Ingenieure (HOAI)* as well as the *VDI-Richtlinie 5200* will be used as basis [14,15]. For this purpose, Chapter 2 explains the fundamental procedure for the application of the BIM method. Chapter 3 shows the different modeling contents of the planning phases, the so-called Level of Development (LoD). In Chapter 4 the process of quality assurance is discussed. Finally, the paper ends with a summary and a conclusion.

2. Fundamentals

2.1 Application of the BIM method

In order to apply the BIM method in organizations and projects, there are already initial recommendations for action [8,9,11]. The procedure is divided into three steps, the formulation of BIM goals, BIM use cases and BIM processes. The BIM goals, i.e., which results are expected through the application of the BIM method, serve as the starting point. Examples of this are the increase in planning quality, cost and time certainty. The BIM use cases are then defined. These concretize the BIM goals as activities. To increase the planning quality, for example, the two use cases geometric collision checking between partial and functional models and quality checking of the models (cf. Chapter 4) can be formulated. The BIM processes, which thus describe the actual working method with BIM, can then be derived from these use cases. This procedure is illustrated in Figure 1. [9,16]

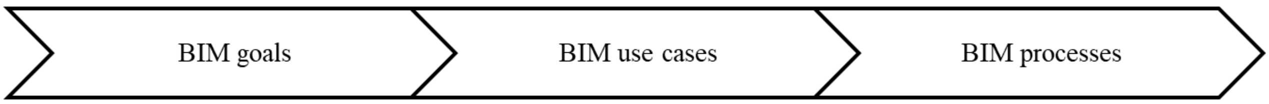


Figure 1: Procedure for the application of the BIM method according to [9,16]

When applying the BIM method in the context of projects, a distinction must also be made between little bim and BIG BIM, and between open and closed BIM (cf. Figure 2). Little bim is the use of BIM software products as a so-called isolated solution. For example, one planner uses BIM software, while the other participants use conventional software products. The opposite of little bim is BIG BIM. Here, all parties involved in the planning process work with digital building models according to the BIM method. The terms open and closed BIM refer to the exchange of data between the stakeholders. In a closed BIM approach, only the software of a specific manufacturer and its proprietary data exchange format is used. In contrast, in an open BIM approach, the software can be freely selected and the manufacturer-independent Industry Foundation Classes (IFC) format is used for data exchange and the BIM Collaboration Format (BCF) for model-based collision communication. [7]

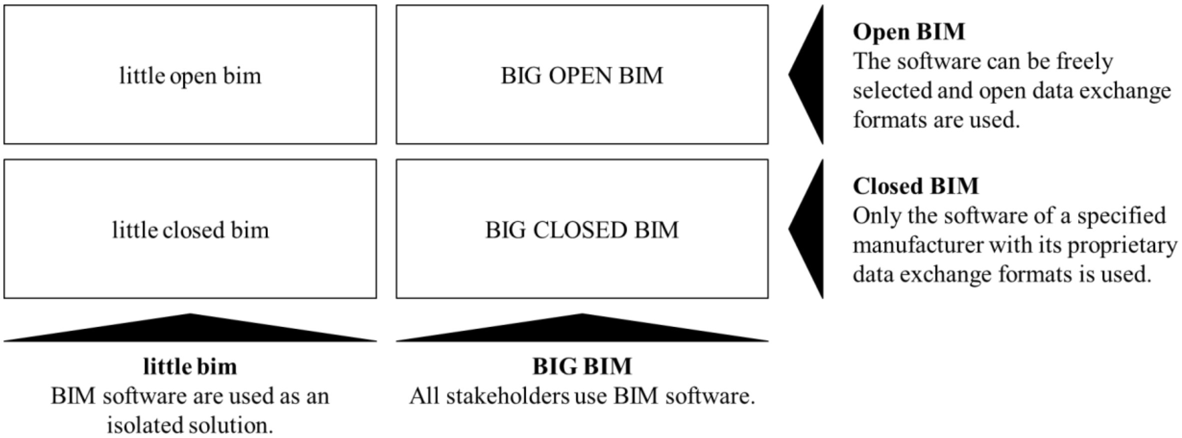


Figure 2: Breadth and data exchange of the application of BIM according to [7]

2.2 Development of the factory layout

Factory layout planning describes the spatial arrangement of operational structural units. The factory is understood as a system in which individual elements are related to each other. The relationships form the structure of the factory, while the elements represent the individual structural units. Depending on the level of factory planning, the structural units can have different characteristics, resulting in two different types of layout with increasing levels of detail, as shown in Figure 3. [4,17]

The first step of factory layout planning is the set-up of rough layouts (ideal and real), in which the functional areas (especially production and logistics areas) within the factory building are shown together with the main transport routes. Subsequently the fine layout is developed, in which the building services and media supply are planned in detail and the operating equipment is precisely positioned. Operating resources are defined as technical systems, equipment and facilities that are used to implement manufacturing, assembly and logistics processes. From a factory planning perspective, operating resources are production resources such as manufacturing machines, assembly resources such as joining tools, and logistics resources such as packaging equipment. All machines, tools, materials as well as energy and media connections are represented and thus the microstructure of the factory is visible. [4,15,17]

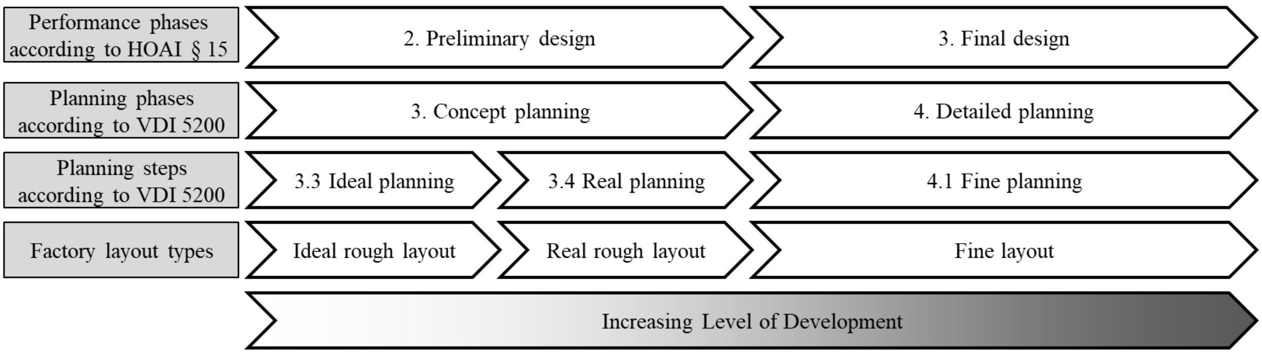


Figure 3: Development of the factory layout during the planning process according to [4,14,15,17]

In contrast to Grundig's explanations [17], the third layout type, the workstation layout, is explicitly dispensed with and its contents are integrated into the fine layout. The layout types are thus adopted according to *VDI-Richtlinie 5200* [15] since increasing the modeling detail within a planning phase is suboptimal for the quality assurance process. This would result in two different levels of modeling detail for this planning phase, and it would not be possible to clearly delineate according to which one quality assurance is to be performed. In addition, the rough layout is separated into ideal and real layout in order to be able to distinguish the content development of the modeling detail in the steps of ideal and real planning in Chapter 3.

Such a development of the modeling detail over time is described in the BIM method with the Level of Development (LoD). The LoD is composed of the geometric modeling level, the Level of Geometry (LoG) and the non-geometric attribution level, the Level of Information (LoI). The literature distinguishes between five general LoDs with possible intermediate levels, 100 to 500, which show the increasing complexity in terms of qualitative granularity (accuracy) and quantitative granularity (richness of detail) of geometric and non-geometric information over the course of a project. However, these levels largely refer to elements from architecture, technical building equipment and structural design and are not transferred to the development of the factory layout yet. An approach for this is presented in the next Chapter 3. [7,18]

3. Level of Development in the phases of factory layout planning

If the development of the factory layout representation is described using the LoD, this results in two levels for the concept as well as the detailed planning. In terms of the LoD in the building design process, these phases run parallel to performance phases 2 and 3 according to the HOAI (cf. Figure 3), resulting in LoD 100 to 200 for the layout planning phases [14,15,19]. The first two layout types, the ideal and the real rough layout, are both to be regarded as a preliminary draft model with LoD 100 and the final fine layout as the draft model with LoD 200. This is shown in Table 1.

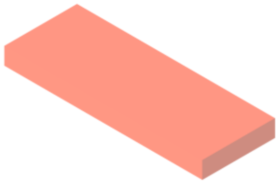
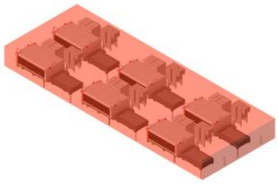
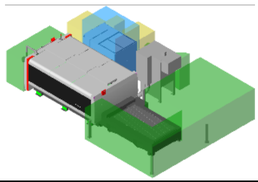
The ideal rough layout is represented as a three-dimensional block layout in which the functional areas of production and logistics are located. The blocks reflect the approximate space requirements and the main route network is also shown. Functional descriptions of the blocks are integrated as non-geometric information and special building design requirements are defined.

The real rough layout is still modeled as a three-dimensional block layout on the area or segment level [15], but the LoG can already be extended to include machine drawings or envelope models. However, care must be taken not to use detailed Computer Aided Design (CAD) design models of machinery and facilities, as these can significantly affect the performance of the overall model. As non-geometric information, static and dynamic loads, required media, caused emissions and lighting requirements should also already be assigned to the individual blocks. If necessary, the blocks can be further subdivided, leaving the area level.

In the final fine layout, the individual resources and workstations are shown in detail. The LoG is clearly deepened with the exact arrangement of the operating equipment, the representation of media connection points as well as maintenance and servicing, logistics and work spaces. In addition, the non-geometric information previously available at area level is assigned to the individual operating equipment and localized there.

Without the clear definition of the LoD for all specialist planners at the start of the project, there is no comparability of the models. The LoD should therefore be an integral part of the Employers Information Requirements (EIR), respectively, the BIM Execution Plan (BEP) in each factory planning project in order to be able to fulfill the BIM goals and use cases based on the Building Information Model. Thus, the LoD is an essential basis for the quality assurance process described in the following chapter.

Table 1: Level of Development in the phases of factory layout planning according to Hausknecht et al. [20]

	LoD 100	LoD 100	LoD 200
	Ideal rough layout	Real rough layout	Fine layout
Illustration			
Description	First ideal arrangement of production and logistics areas as preliminary draft model	Investigation of layout variants and determination of the preferred variant as preliminary draft model	Detailed layout up to the representation of the individual operating resources and workstations as draft model
LOG	Three-dimensional block layout with the main route network of the factory with approximate space requirements	Three-dimensional block layout with the main route network of the factory with machine drawings or envelope models	Detailed arrangement of equipment, representation of media connection points as well as, maintenance and service, logistics and work spaces with specific dimensions, location and orientation
LOI	Functional description of the blocks including special requirements	First general alphanumeric information such as static and dynamic loads, required media and causing emissions as well as lighting requirements	Detailing of all alphanumeric information, such as the assignment of media connection values to the media connection points

4. Assurance of the planning quality

When it comes to assurance of planning quality, the focus is primarily on the BIM goal of increasing planning quality. However, if this BIM goal is achieved, this leads directly to an increase in cost and time certainty because defects such as those at Berlin's BER Airport are avoided at an early stage [21]. Accordingly, by achieving the BIM goal of increased planning quality, a significant contribution can be made to increasing the degree to which time and cost targets are achieved in factory planning projects.

From this, the two BIM use cases geometric collision checking between partial and functional models and quality checking of the models are derived. In the following, these use cases are assigned to the phases of layout planning and described with the corresponding process.

4.1 BIM use case geometric collision checking

The use case of geometric collision checking between partial and functional models describes the merging of the individual models, their mutual checking for geometric collisions and the subsequent communication of the collisions. For the execution of the use case, it is necessary that models of different disciplines are or at least that several partial models are available in order to be able to check them against each other. Thus, in a little bim approach, this BIM use case is only possible as a check between partial models. [9,11]

In layout planning, geometric collision checking is usually only useful from the real planning phase onwards, since any collisions in ideal planning are possible but still negligible. This is due to the relatively low LoD of the production system model in the form of a block layout and to the subsequent generation of planning variants, which in turn can differ significantly from the ideal layout. The models should therefore be roughly coordinated with each other, but a software-based collision check does not usually have a positive cost-benefit ratio. [19]

Software-based collision checks are more reasonable in the context of real planning, e.g. whether a production area collides with larger building structures like walls. Detailed collision checks are only useful from the detailed planning phase onwards, as the corresponding LoD is only reached there. For example, it can be checked whether a maintenance and servicing area of a production facility collides with a column.

4.2 BIM use case quality checking

Based on the BIM use case geometric collision check between partial and functional models, the following section focuses on the quality checking of the models in the form of an analysis of the spatial requirements of possible layout variants in terms of their properties in relation to their technical feasibility. For this purpose, it is necessary to design different rule checks to examine restrictions on technical feasibility regarding legal, normative, product-specific or component-specific interfaces and dependencies. [22]

The evaluation criteria for quality assurance are to be analyzed separately in relation to the respective definition of targets, and based on this, corresponding regulatory checks need to be developed. In this context, the examination of legal issues can be identified as an important field of action for the development of quality checks. Accordingly, legal requirements can be identified as first field of action, such as the adherence to the Industrial Building Guideline, e.g. ensuring a maximum escape route length (cf. Figure 4) or the Workplace Guideline, e.g. guaranteeing an appropriate level of illumination in an area of the layout analogous to the work activities to be performed therein. [22]

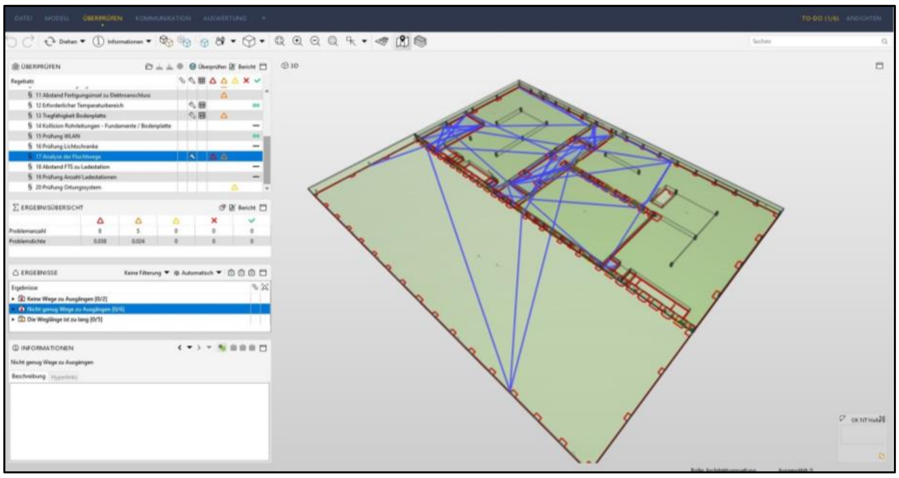


Figure 4: Example rule check escape route analysis [22]

In addition, the second field of action, possible product-specific influencing criteria for the case as well as product information, such as material properties, must be analyzed and, if necessary, transferred to the analysis of technical feasibility by means of standard tests. Accordingly, the second field of action describes product-specific influencing parameters, such as manufacturer information on the minimum concrete quality of the fastening substructure for the application of a building product. [22]

Potential component-specific interfaces and, if relevant, existing dependencies between individual components represent a third field of action with potential for the development of rule-based checks. Accordingly, in the third field of action, interfaces and dependencies between individual building components are presented and examined in terms of possible geometric but also qualitative collisions between one another. [22]

For the implementation of the BIM use case, it is necessary, analogous to Chapter 4.1, that models of different disciplines or at least that several partial models are available in order to be able to check them in relation to each other. Thus, in a little bim application, this BIM use case is only possible as a check between partial models and is only possible in layout planning from the real planning phase onwards, since the first non-geometric data is available in the models, which is indispensable for a quality check.

Within the framework of real planning, only conceptual quality checks are useful, e.g. whether the energy requirements of a production area can be covered by the planned energy supply. Detailed checks are only recommended from the detailed planning phase onwards, since again, analogous to Chapter 4.1, the correspondingly required LoD is achieved there. For example, it can be checked whether the load-bearing capacity of the floor is sufficient for a particular piece of equipment or not.

4.3 Quality assurance process

These use cases result in the following BIM process. A BIM coordinator and at least two BIM authors must be available as BIM roles. The BIM coordinator takes over the merging of the functional or partial models, the collision and quality checking as well as the communication of collisions and quality reports and is thus responsible for ensuring quality. The BIM authors create the BIM models and are thus responsible for modeling according to the required LoD. However, before the models are handed over by the authors to the coordinator, it is advisable to first subject their own model to quality assurance. For this purpose, the adherence to the specified designations, the adherence to the agreed model structure, the correct placement within the coordination body, the use of the uniform axis grid, the adherence to the coordinate system as well as the project zero point, the use of the correct model units, a space-filling modeling of the spaces as well as the internal collision freedom should be checked. The two use cases of geometric collision checking and quality assurance should thus be implemented within a functional discipline, as in a little bim approach, before they are applied across disciplines.

BIM authoring software and collision checking software are used as tools for this purpose. A Common Data Environment (CDE) can also be used as a central exchange platform. The data transfer points, i.e. data drops, are to be selected project-specifically and depending on the project progress. In real planning, the models are checked rather sporadically for collisions. In fine planning, on the other hand, the models are merged at regular intervals, e.g. at intervals of one to six weeks. The IFC and BCF formats are used for data exchange in an open BIM approach. The resulting BIM process is shown in Figure 5.

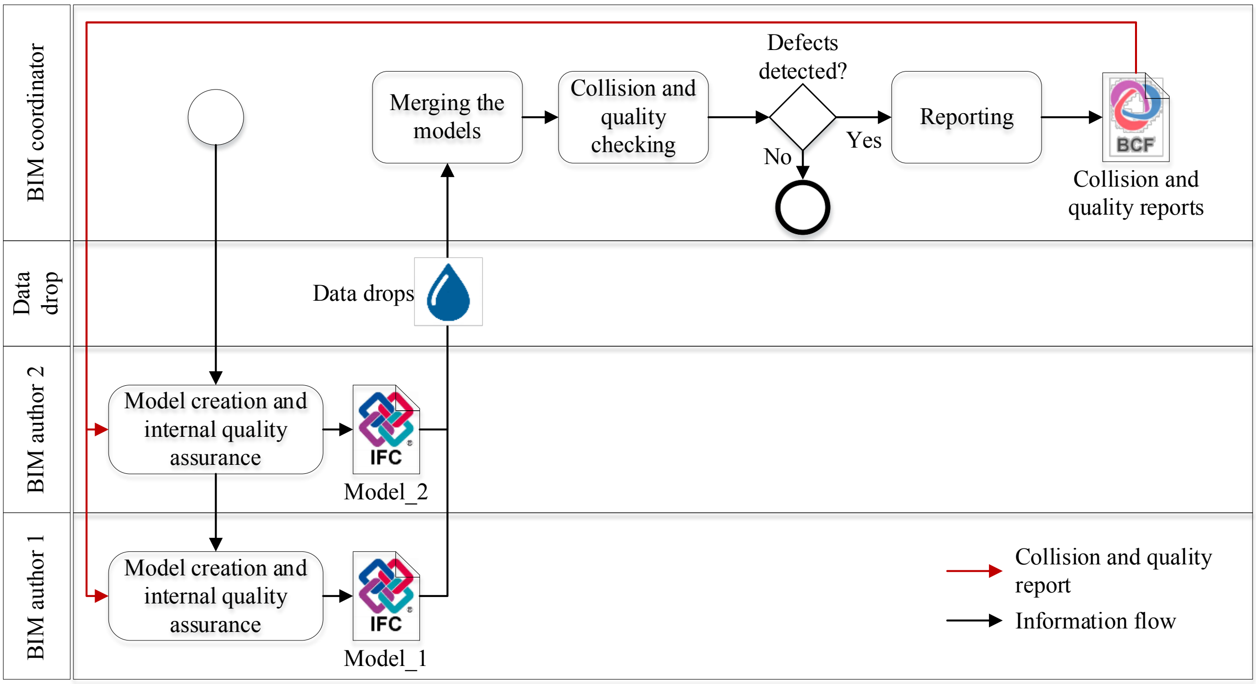


Figure 5: Quality assurance process according to [19]

5. Summary and conclusion

In this paper, a modeling guideline regarding the geometric and non-geometric level of detail in the factory layout planning process, i.e. the Level of Development, is presented. Focusing on the BIM goal of improving planning quality, two BIM use cases, the geometric collision checking of functional and partial models and the quality checking of models are described and merged to a quality assurance process. Thereby, the focus is laid on the layout planning process, since in this phase the production system merges with the building to form the factory and a large part of the planning interaction between the individual trades takes place.

Based on the average of 5,820 completed factory and workshop buildings from 2011 to 2020 in Germany with a total cost volume of 4.7 billion euros and a share of 60% of factory planning projects in which cost targets are missed by about 10%, this results in error costs of about 283 million euros per year [5,23]. The presented potentials of the BIM methodology offer the possibility to avoid these error costs. But how and whether this can also be realized by the approach presented must be evaluated and assessed in the next step on the basis of initial use cases. There are two use cases from the metal processing industry, one Greenfield and one Brownfield project. The Greenfield project is about 25,000 square meters of production and the Brownfield project is about 2,000 square meters. The evaluated and validated results will subsequently be published.

Furthermore, to generate a baseline for BIM-based factory layout planning, more BIM goals and their related use cases will be investigated. Afterwards, this procedure can be extended on the whole factory planning process, as well as the whole factory life cycle. Parts of this follow-up work will be addressed within the framework of *VDI Guideline 2552 part 11.8.1 BIM use case factory layout planning, the VDI expert recommendation BIM-based factory planning* and the *buildingSMART expert group open BIM in factory planning*.

References

[1] Statista, 2021. Anteil der Wirtschaftszweige an der Bruttowertschöpfung in Deutschland im Jahr 2020.

[2] Abele, E., 2011. Zukunft der Produktion: Herausforderungen, Forschungsfelder, Chancen. Hanser, München.

[3] Pawellek, G., 2014. Ganzheitliche Fabrikplanung: Grundlagen, Vorgehensweise, EDV-Unterstützung, 2nd ed. ed. Springer Berlin / Heidelberg, Berlin, Heidelberg.

[4] Wiendahl, H.-P., 2014. Handbuch Fabrikplanung: Konzept, Gestaltung und Umsetzung wandlungsfähiger Produktionsstätten, 2., überarbeitete und erweiterte Auflage ed. Hanser; Ciando, München, Wien, München.

[5] Reinema, C., Pompe, A., Nyhuis, P., 2013. Agiles Projektmanagement. Zeitschrift für wirtschaftlichen Fabrikbetrieb 108 (3), 113–117.

[6] Packwitz, C., Faust, A., 2022. Fehlerkostenbilanz 2020: Rund 18 Milliarden Euro verbauter Schaden. BauInfoConsult. https://bauinfoconsult.de/presse-fehlerkostenbilanz-2020-rund-18-milliarden-euro-verbauter-schaden/. Accessed 16 March 2022.

[7] Borrmann, A., König, M., Koch, C., Beetz, J. (Eds.), 2021. Building Information Modeling: Technologische Grundlagen und industrielle Praxis, 2., aktualisierte Auflage ed. Springer Vieweg, Wiesbaden.

[8] Bundesministerium für Verkehr und digitale Infrastruktur, 2015. Stufenplan Digitales Planen und Bauen: Einführung moderner, IT-gestützter Prozesse und Technologien bei Planung, Bau und Betrieb von Bauwerken.

[9] Meins-Becker, A., Kaufhold, M., 2021. BIM-Handlungsempfehlung: für die kommunalen Bauverwaltungen und die kommunale Gebäudewirtschaft in Nordrhein-Westfalen. Ministerium für Heimat, Kommunales, Bau und Gleichstellung des Landes Nordrhein-Westfalen. www.mhkbg.nrw. Accessed 4 February 2022.

[10] Bryde, D., Broquetas, M., Volm, J.M., 2013. The project benefits of Building Information Modelling (BIM). International Journal of Project Management 31 (7), 971–980.

[11] Tulke, J., Stein-Barthelmes, I., 2021. Umsetzung des Stufenplans „Digitales Planen und Bauen". planen-bauen 4.0 GmbH. https://bim4infra.de/. Accessed 4 February 2022.

[12] Neuhäuser, T., Chen, Q., Rösch, M., Hohmann, A., Reinhart, G., 2020. Building Information Modeling im Fabriklebenszyklus. Zeitschrift für wirtschaftlichen Fabrikbetrieb (s1), 66–69.

[13] Rieke, L., Schäfer, S.F., Hingst, L., Hook, J., Peter, N., 2021. Einsatz von BIM in der Fabrikplanung/Use of BIM in factory planning. wt 111 (11-12), 881–886.

[14] Koeble, W., Zahn, A., 2021. Die neue HOAI 2021: Text und Erläuterungen, 3. Auflage ed. Werner Verlag; Wolters Kluwer Deutschland GmbH, Hürth.

[15] Verein deutscher Ingenieure, VDI-Gesellschaft Produktion und Logistik (GPL), 2011. Fabrikplanung: Planungsvorgehen. Beuth 03.100.99.

[16] Verein deutscher Ingenieure buildingSMART, VDI-Gesellschaft Bauen und Gebäudetechnik (GBG), 2021. Building Information Modeling: Informationsaustauschanforderungen zu BIM-Anwendungsfällen. Beuth 35.240.67.

[17] Grundig, C.-G., 2015. Fabrikplanung: Planungssystematik - Methoden - Anwendungen, 5., aktualisierte Aufl. ed. Hanser, München.

[18] Liebsch, P., Sautter, H., 2018. BIM Praxisleitfaden: LOD / LOI Definitionen. Informationen zur Detaillierungs- und Informationstiefe. http://www.bim-blog.de/bim-praxisleitfaden-1-0/. Accessed 4 February 2022.

[19] Neuhäuser, T., Michaeli, P., Lenz, L., Hohmann, A., Matschinsky, F., Madl, F., Henkelmann, R., 2021. Collaborative Factory Layout Planning With Building Information Modeling. Conference on Production Systems and Logistics 2, 699–708.

[20] Hausknecht, K., Liebich, T., 2018. BIM-Kompendium: Building Information Modeling als neue Planungsmethode, 2. überarbeitete und erweiterte Auflage ed. Fraunhofer IRB Verlag, Stuttgart.

[21] Metzner, T., Keilani, F. Dicke Luft wegen zu schwerer BER-Ventilatoren: Statikprobleme in Schönefeld. Tagesspiegel.

[22] Lenz, L., 2020. Bewertungssystem zur Entscheidungsunterstützung von Fabrikgebäudeanpassungen auf Basis von Building Information Modeling. Dissertation.

[23] Statistisches Bundesamt (Destatis), 2021. Baufertigstellungen im Hochbau: Deutschland, Jahre, Bautätigkeiten, Gebäudeart/Bauherr.

Biography

Thomas Neuhäuser (*1990) is group leader for collaborative factory planning at the Fraunhofer Institute for Casting, Composite and Processing Technology IGCV. He is chairman of the VDI-guideline committee BIM-based factory planning and spokesman of the buildingSMART expert group open BIM in factory planning.

Lisa Lenz (*1986) is a civil engineer and works as Post-Doc at the department of construction management at TU Dortmund University. Her research focuses on Building Information Modeling, digitization of the construction industry and research into data-driven rule checks of design services. Dr. Lisa Lenz is managing director of Building Information Cloud GLWG GmbH and spokeswoman of the buildingSMART expert group open BIM in factory planning.

Kai Weist (*1989) is a civil engineer and works as a PhD at the department of construction management at the TU Dortmund University. The main focus of his research lies in the adaptation of Building Information Modeling to factory planning processes and in the digitization of construction processes overall. Since 2020 Kai Weist is managing director and founder of the Building Information Management GLW GmbH.

Andrea Hohmann (*1983) studied aerospace engineering at the University of Stuttgart and received her doctorate in 2019 at the Technical University of Munich on the topic "Life cycle assessment of manufacturing processes for CFRP structures for the identification of optimization potentials". Since 2012, Dr.-Ing. Andrea Hohmann is head of the department sustainable factory planning at the Fraunhofer IGCV.

Rüdiger Daub (*1979) is the holder of the Chair of Production Engineering and Energy Storage Systems at the Technical University of Munich and director of the Fraunhofer IGCV. After studying Electrical Engineering and Information Technology at the Karlsruhe Institute of Technology (KIT), he earned his doctorate at the Technical University of Munich (TUM). From 2012 to 2021, he held several positions at BMW Group Munich, most recently as Head of Technology Development and Prototype Construction of Lithium-Ion Cells.