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Collaborative Factory Layout Planning With Building Information Modeling

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Abstract

Manufacturing companies are facing an increasingly turbulent environment. 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 the lack of interoperability. Therefore, new ways have to be found in factory planning to overcome these problems. Building Information Modeling (BIM), which is used in the construction industry, provides a promising method for collaboration and interaction in complex projects. Therefore, an approach is presented to systematically implement the BIM method in the factory layout planning process. The aim of this approach is to achieve a higher degree of collaboration between the individual specialist planners in earlier planning phases in order to reduce time and costs over the entire project and to lead to better and more valid planning decisions and results. For this purpose, the individual roles in the planning process are defined, a process diagram for layout planning is drawn up, and a basic data set is specified for the systematic entry of the trades.

Keywords

Factory Planning; Building Information Modeling; Layout Planning

1. Introduction

The manufacturing industry is one of Germany's most important economic sectors, accounting for 22.9% of gross domestic product [1]. However, companies in the economic sector are facing challenges and trends such as globalization, dynamization of product life cycles and climate change. These circumstances lead to a turbulent market environment for manufacturing companies. Therefore, innovations are developed more regularly, to which the production system has to be adapted within the shortest possible time. Production adjustments are hence becoming more frequent and must be implemented much faster. Factory planning thus becomes a continuous task. [2–4]

The central target variables of planning projects are time, costs and quality. While the quality targets are generally met, the time targets are missed in about 60% of projects and the cost targets in approximately 72%. This is partly due to a lack of interoperability between the different planning participants [5]. A study by Gallagher et al. [6] concludes that the lack of interoperability in the facilities industry costs $15.8 billion per year in the U.S. alone. To overcome these problems, new planning approaches must be developed and applied in factory planning projects.

The methodology of BIM starts exactly at this point. BIM is a collaborative planning method that allows the systematic exchange of data and information between stakeholders throughout the entire lifecycle of a building based on digital models, which contain geometrical data as well as non-geometrical data like floor loadings. With an agile planning approach and standardized exchange formats in the openBIM process, the lack of interoperability can be avoided and processes are more efficient. Current studies show that the use of BIM in planning projects can reduce time and costs by up to 25%. [7–9]

While BIM has been mandatory for public infrastructure projects in Germany since 2020, there have been few known use cases in factory planning [10]. The main reasons for this are the lack of support for cross-discipline data exchange formats and the systematic separation of production system and building planning procedures [9]. To overcome these shortcomings, this paper introduces a BIM-based collaborative way of working in factory planning projects. 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. For this purpose, chapter 2 explains the fundamental differences between classical and BIM-based planning procedures. Chapter 3 sets out and subsequently analyzes the information exchange requirements between the single specialist planners. In chapter 4 the implications for the factory layout planning process are discussed. Finally, the paper ends with a summary and a conclusion.

2. Fundamentals

2.1 Conventional planning procedure

Factory planning is composed of the planning of the production system, which is responsible for the value creation of the company, and the building, which forms the envelope around the production. The VDI guideline 5200 part 1 [11] describes the classical planning approach of the production system. According to this, the planning process is structured in seven successive phases, ranging from phase 1 setting of objectives to phase 7 ramp-up support. The "Honorarordnung für Architekten und Ingenieure" (HOAI 2021) [12] describes the planning procedure for construction projects in Germany. Therein, nine different service phases are passed through from phase 1 the establishment of the product basis to phase 9 the project management and documentation. Figure 1 shows the assignment of the phases of production system and building planning to the factory planning process. [11,12]

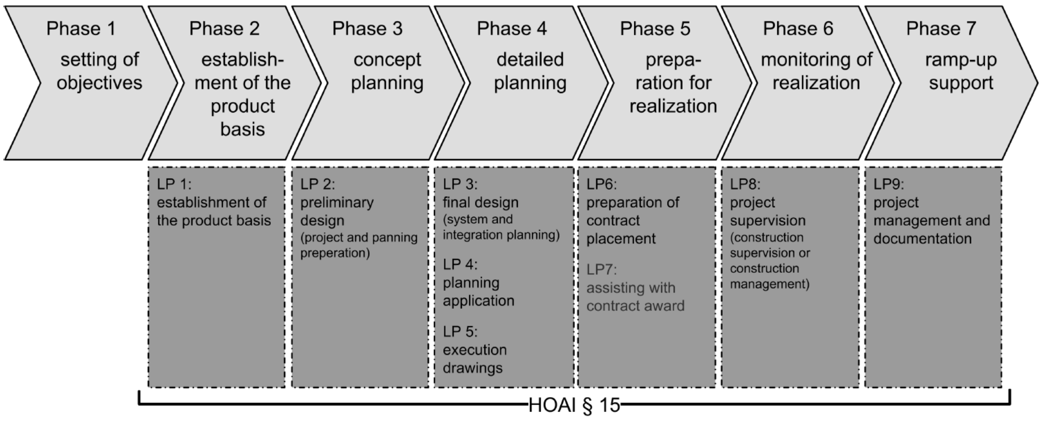

Figure 1: Assignment of performance phases according to HOAI, Article 15, to the planning phases [11]

Layout planning takes place in phases 3 and 4 of the production system planning process. It is divided into three steps, ideal planning, real planning and fine planning. The input parameters for ideal planning are the dimensioned resources, a rough logistics concept and a scale function diagram showing space assignments. In the ideal planning itself, structural units such as resources are then ideally arranged in relation to one another. Several layout variants can be designed, for each of which a building envelope is designed. In the real planning, the layout variants are merged with the building envelope and the structural framework is designed. Subsequently, the generated variants are evaluated monetarily, quantitatively and qualitatively and a feasible factory concept is decided upon. In the subsequent fine planning, the material, information and communication flows, the equipment, the work organization and the media supply concept are determined. This results in a fine layout with specified operating resources and a complete building design, which can then be used to prepare the permit applications. The phases of layout planning of the production system correspond to the phases 2 and 3 of the HOAI 2021. [11]

However, the systematic separation of production system planning and building planning in two different directives, respectively regulations, often leads to a strict separation of the two in projects. In particular, short-term adjustments in both disciplines lead to misunderstandings, planning errors, uncoordinated processes, delayed results as well as non-compatible data formats and thus to a failure to meet time and cost targets in factory planning projects.

2.2 BIM-based planning procedure

BIM-based planning approaches attempt to overcome these problems by systematically connecting the individual planning disciplines, by bringing forward planning and decision-making processes, as shown in figure 2, and by establishing the standardized data exchange format Industry Foundation Classes (IFC) in the openBIM process. Over 300 different software tools for various specialist planners already support IFC, which greatly simplifies the exchange of data and information and counteracts the lack of interoperability [13]. In addition to IFC, a second exchange format is relevant for a BIM-supported planning process, the so-called BIM collaboration format (BCF) [14]. This vendor-neutral format is used to exchange coordination messages in change management of a design process. If, for example, a collision occurs between different specialist models, a report with the position, perspective, affected object and text can be distributed to the specialist planners. [7]

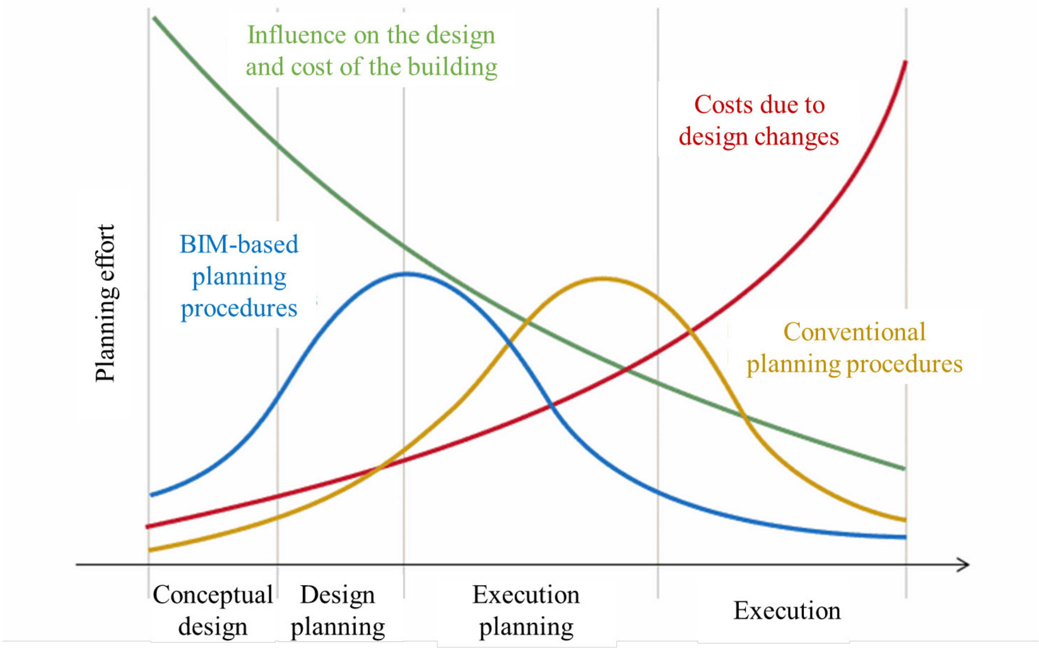

Figure 2: Forward shifting of planning and decision making processes in BIM-based planning procedures [7,15]

In addition to the data exchange formats, the individual roles in the planning process are also crucial. Additionally, to the individual specialist planners, a so-called BIM manager is introduced, who is responsible for several tasks, e.g. to take over quality assurance in the project. To this end, the BIM manager regularly brings together the isolated planning statuses of the specialist planners and checks them for clashes. The specialist planners themselves are divided into authors and coordinators of their subject-specific BIM model. The authors provide the content for the specialized model. The coordinator of a specialist discipline is responsible for the provision and the quality of the developed model. The authors and coordinators thus always cover a specialist discipline, while the BIM manager should be independent of the discipline. [7,14]

To implement a BIM-based approach in a project, the BIM targets and use cases must be defined after setting the project and factory objectives. The concrete implementation of the BIM methodology in the project is then derived from these. It is advisable to create an Information Delivery Manual (IDM) in order to define which planning participants have to transfer which data to whom and at what time. These data delivery points are referred to as data drops [16]. However, such an IDM is not yet available for general layout planning process and is therefore described in the following chapter.

3. IDM for the BIM use case factory layout planning

To close this gap and generating the IDM for the use case of factory layout planning, an inductive research approach was chosen. In several workshops with factory planning experts from industry and research, it was defined which planning participants have to transfer which data to whom and at what time.

In the presented approach, only the layout of the production facilities is considered in layout planning. Influencing factors such as the logistics system, work aids or even the people in the factory are not taken into account. Moreover, no distinction is made between BIM authors and coordinators, but only the role of the specialist planning discipline as a whole is considered.

3.1 Description of roles

As shown in table 1, there are four basic planning disciplines and the BIM manager in the factory layout planning process. The disciplines are the production system planner, who plans the layout, the architect, who designs the building envelope, the structural engineer, who plans the structural framework, and the building equipment (MEP) planner, who plans e.g. the media supply and disposal.

Table 1: Description of roles in the factory layout planning process

Role	Description
BIM manager	Coordination of the individual specialist planners, ensuring quality of the planning process and the absence of clashes as well as control of change management
Production system planner	Plans the layout from ideal to real to fine
Architect	Plans the building envelope
Structural engineer	Plans the structural framework including the foundations
MEP planner	Plans the media supply system including the IT connection as well as electrical engineering and the discharge of emitted media around the production facilities

3.2 Process diagram

The stakeholders intervene in the planning process at different points in time and develop its contents. Figure 3, 4 and 5 show the interlocking as Business Process Model and Notation diagrams throughout the layout planning phases.

The process begins in the ideal planning phase (figure 3) with the BIM manager. The manager creates a coordination body, as an empty coordination model with a coordinate system. This ensures that each discipline model is planned in a uniform coordinate system. This coordination model is passed on to the production system planner as an IFC file. The latter carries out the ideal layout planning and thus generates the first model of the production system (Production system model_v1). In contrast to the theoretical approach, in which several variants are created, often only one ideal variant is generated. This is used again and again as an ideal benchmark in the further course of planning.

Subsequently, the architect begins to define the building restrictions. The models are always transferred as IFC files and normally there are no iterations between the production system planner and the architect. Afterwards, the next planning phase begins.

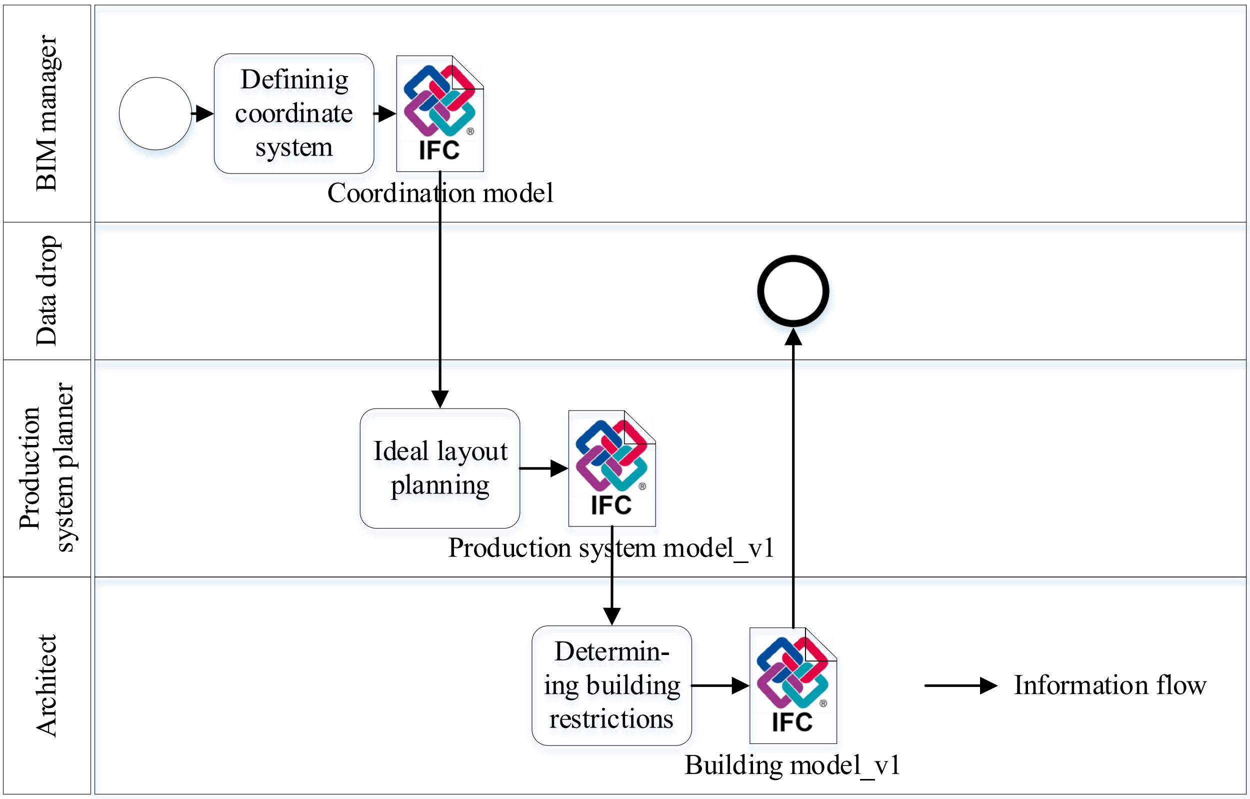

Figure 3: Process diagram for the ideal planning

The structural engineer and building services engineer are involved in the real planning (figure 4). At the beginning of this phase, the production system planner creates several real layout variants based on the ideal layout and the building restrictions. These variants can follow different target points such as expandability, material flow optimization or lead times. These variants are then roughly planned and evaluated by the other planning disciplines. It must be ensured that a relatively high level of abstraction is still maintained, but that the individual variants can still be validly evaluated by the individual specialist planners. Even in this phase, it is not necessary to follow a purely sequential process; instead, there may be several iterations.

This phase is followed by a clash detection, after the final data delivery as a big data drop. It is crucial that the models are collision-free and that the project and factory objectives are met. The BIM manager performs these tasks, for both the production system as well as the building planning. Adherence to the objectives is decisive in that the degrees of freedom of the planning and thus the specified restrictions must be moderated between the production system planner and the architect. For example, an objective such as the transformability of the building must not be allowed to get out of hand when planning should be optimized for material flow. The moderation of the focus is decisive because, on the one hand, the building can be expected to have a significantly longer service life than the production system and its adaptability can therefore be very important. On the other hand, an actual greenfield must not become a brownfield planning due to overly tight building restrictions, as a result of which planning close to the ideal layout is no longer possible. To ensure that there are no clashes, the BIM manager must merge the individual models in a collision check. If clashes are detected, change orders are distributed to the specialist planners as BCF files.

If there are no collisions or if all collisions are eliminated, a decision will be made for one of the variants based on the evaluation of the individual planners (Factory model_v1). The ideal variant is used as a benchmark and the evaluation takes place quantitatively, monetarily and qualitatively. Afterwards, the fine planning begins.

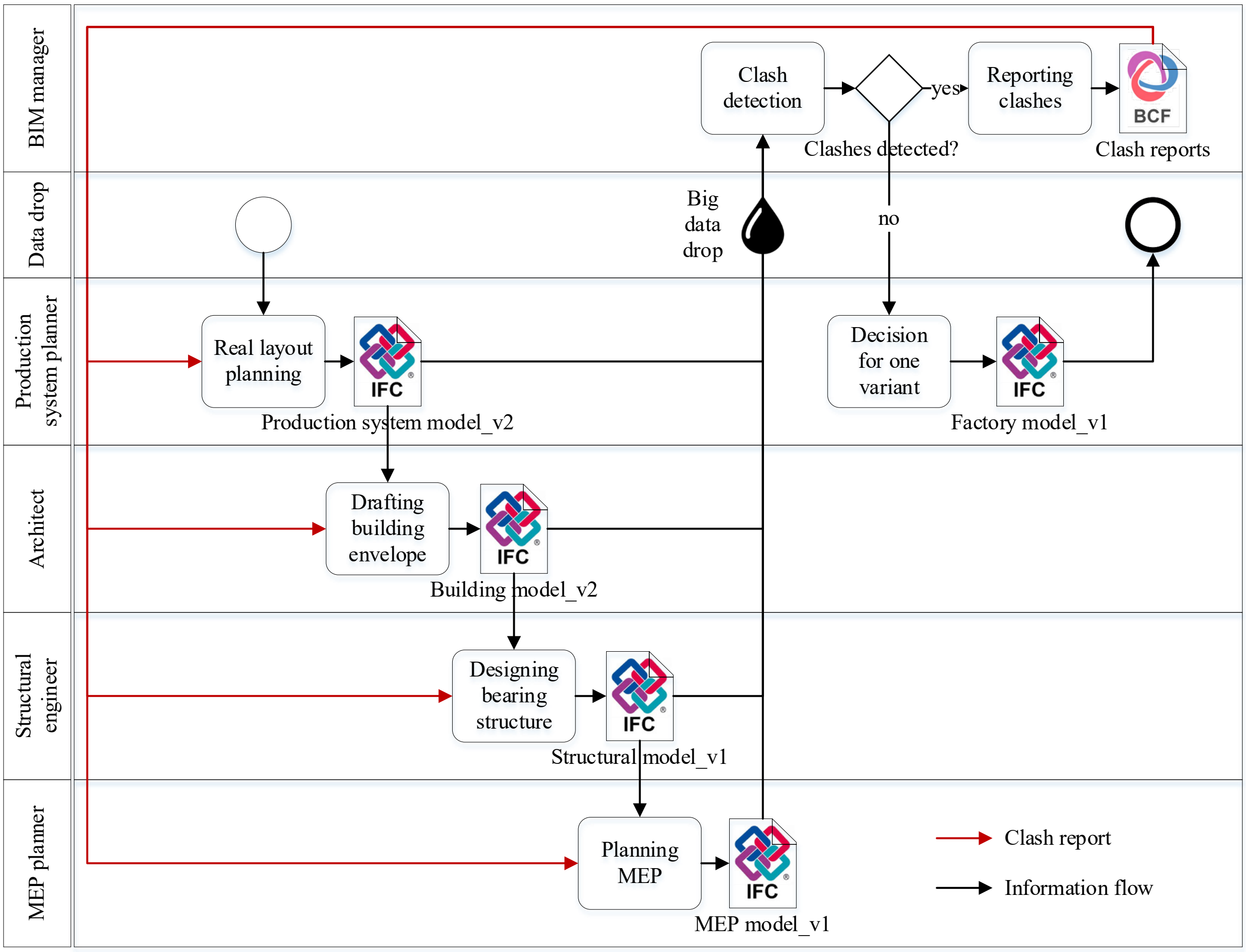

Figure 4: Process diagram for the real planning

In fine planning as in real planning, all planning disciplines are involved (figure 5). Here, there can be significantly more iteration loops, since the high level of detail in planning means that significantly more data and information must be exchanged. So the final big data drop at the end of the phase is joined by many small data drops in the iteration loops. These are delivered every one to six weeks, depending on the agreed interval duration, also called sprints agile planning approaches. Once the collision check has been completed, the factory model (Factory model_v2) is available and the permit applications can be prepared.

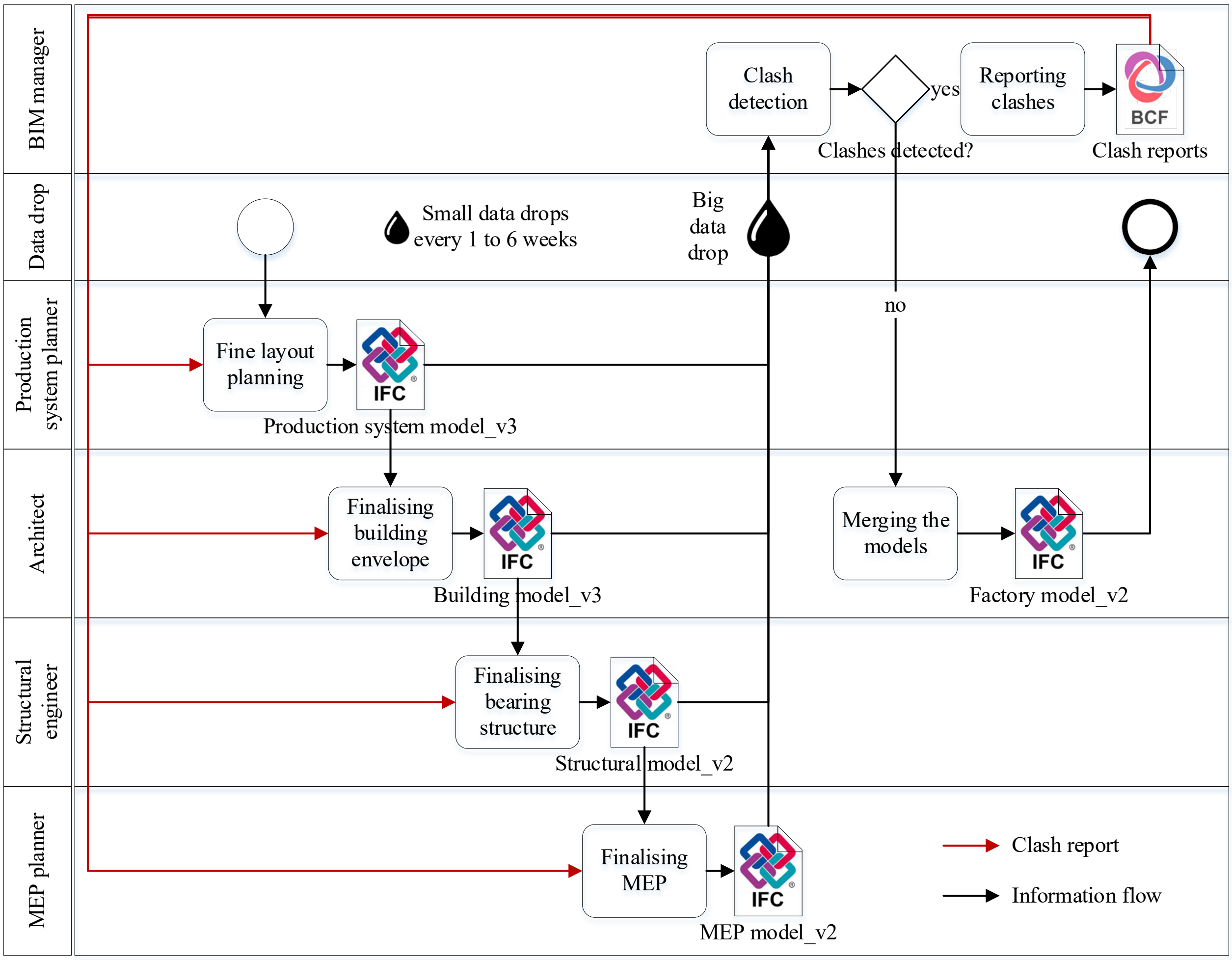

Figure 5: Process diagram for the fine planning

3.3 Exchange Requirements

In the case of exchange requirements, the second production system model (Production system model_v2) is of particular importance. In a BIM-based planning procedure, this must already contain a first data set on which the other specialist planners can carry out their initial rough planning. This information, which is all related to the production facilities, includes the spatial arrangement, the geometric dimensions, the weight, the vibration behavior, the media requirements and connections, the electrical power requirements and connections, the emitted media quantities and their connection points, certain safety as well as fire protection requirements and IT connections. The information types as well as the required information are shown in detail in table 2.

Table 2: Exchange Requirements for the second production system model

Type of information	Information needed
Spatial arrangement	Spatial arrangement in relation to other production facilities
Geometric dimensions	Description of outer contours
Weight	Weight
Vibration behavior	Description of frequency and amplitude of the vibration behavior
Media requirements	All operating media such as cooling lubricants, process gases, compressed air or even water according to type and quantity
Media connections	Place and type of connection
Electrical power requirements	Type and quantity of electrical demand
Electrical power connections	Place and type of connection
Emitted media quantities	All emitted media such as exhaust air, heat, used cooling lubricants or also waste water according to type and quantity
Emitted media connections	Place and type of connection
Safety requirements	All safety-related requirements such as protective fences and safety zones
Fire protection requirements	All fire protection-related requirements like sprinklers
IT connections	Place and type of connection

This data set does not have to be complete and may contain some uncertainties, but should be updated and exchanged throughout the planning process. The quality assurance of this process can be ensured by the BIM manager through regular quality gates.

4. Implications for the factory planning process and discussion

A BIM-based factory planning approach leads as shown in chapter 3 to a significant increase in planning efforts in the early phases. For example, the production system planner must provide the most detailed information possible on the production facilities as early as the second model so that the other specialist planners can build on this. In addition, the technical building equipment planner is involved in the planning process at a much earlier stage and has to evaluate planning alternatives for different layout variants. This definitely leads to an increased planning effort, which, however, can make the subsequent phases less time-consuming and lead to better planning results due to the clearly well-founded planning. In addition, this leads to a more valid cost estimation for the client.

If the opportunity for better planning results is set against the risk of increased planning effort in terms of time and costs, the risk should not be shied away from. Only 1% of the costs incurred in the life cycle of a structure are attributable to the planning phase, whereas 90% are incurred in the operating phase. The remaining 9% is accounted for by implementation. Accordingly, a trade-off between a reduced planning effort and a worse planning result is only worthwhile from a factor of 90. [17]

5. Summary and conclusion

In the paper, an approach for a BIM-based factory planning procedure was presented. Based on the role definitions in the planning process, a process diagram for factory layout planning was developed and the information exchange requirements for the first production system model were defined. With the help of this model, the other disciplines can be integrated into the planning process much earlier. This early involvement can result in additional costs in the early planning phases, which can be more than offset by a reduction in the workload in the later phases or a reduction in costs in factory operation and the whole life cycle of a building. In addition, BIM has the potential to support the achievement of cost and time targets in factory planning projects by the systematic integration of production system and building planning processes, and the standardized exchange of information can significantly reduce costs due to a lack of interoperability.

The next step is to complete the information exchange requirements for all handover documents to generate a complete IDM for the factory layout planning process. The Model View Definitions can then be derived from this and an IFC extension can be made to include production system data. This is currently being developed within the framework of *VDI Guideline 2552 part 11.8 BIM – factory planning* and the *buildingSMART Roundtable openBIM in factory planning*. In addition, the approach will be applied in pilot projects to analyze the implications in reality.

References

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

[2] Abele, E., Reinhart, G., 2011. Zukunft der Produktion: Herausforderungen, Forschungsfelder, Chancen. Carl Hanser Fachbuchverlag, s.l., 262 pp.

[3] Pawellek, G., 2014. Ganzheitliche Fabrikplanung: Grundlagen, Vorgehensweise, EDV-Unterstützung, 2. Aufl. ed. Springer Vieweg, Berlin, 443 pp.

[4] Wiendahl, H.-P., Reichardt, J., Nyhuis, P., 2014. Handbuch Fabrikplanung. Carl Hanser Verlag GmbH & Co. KG, München.

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

[6] M. Gallaher, A. O'Connor, John L. Dettbarn, L. T. Gilday, 2004. Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry, in: .

[7] Borrmann, A., König, M., Koch, C., Beetz, J. (Eds.), 2015. Building Information Modeling: Technologische Grundlagen und industrielle Praxis. Springer Vieweg, Wiesbaden, 591 pp.

[8] Dr. Wieselhuber & Partner GmbH, 2018. BIM – Are you Ready?: Strategische und operative Gestaltungsimpulse für die Bauindustrie, München.

[9] Neuhäuser, T., Chen, Q., Rösch, M., Hohmann, A., Reinhart, G., 2020. Building Information Modeling im Fabriklebenszyklus. ZWF 115 (special), 66–69.

[10] 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, Berlin.

[11] Verein Deutscher Ingenieure, 2011. Fabrikplanung: Planungsvorgehen. Beuth 03.100.99.

[12] 2013. Verordnung über die Honorare für Architekten- und Ingenieurleistungen: HOAI.

[13] Jeffrey Ouellette. Software Implementations. https://technical.buildingsmart.org/resources/software-implementations/. Accessed 31 March 2021.

[14] Verein Deutscher Ingenieure, 2018. Building Information Modeling: Begriffe. Beuth 35.240.67.

[15] Patrick MacLeamy, 2004. Collaboration, Integrated Information, and the Project Lifecycle in Building Design and Construction and Operation. https://docplayer.net/61412208-Collaboration-integrated-information-and-the-project-lifecycle-in-building-design-construction-and-operation.html. Accessed 21 March 2021.

[16] Verein Deutscher Ingenieure und buildingSMART, 2020. Building Information Modeling: Informationsaustauschanforderungen. Beuth 35.240.67.

[17] 2019. The New Zealand BIM handbook: A guide to enabling BIM on building projects, Version 3.1 ed. [BIM Acceleration Committee], [Wellington], 1 online resource.

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 2552 Part 11.8 BIM – factory planning and spokesman of the buildingSMART Roundtable openBIM in factory planning.

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Rayk Henkelmann (*1977) is owner, manager and leading an engineering company for technical building equipment, specialized for electrical planning and consulting. He is member of the VDI and buildingSMART.