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Supporting BIM-driven Factory Design by Engineering Data Management Capabilities

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Abstract

Nearly six thousand factory buildings requiring approval in Germany with a volume of almost 5 billion euros per year. According to recent studies, more than two-thirds of these buildings miss their cost targets by at least 10 percent. Building Information Modelling (BIM) promises considerable potential for optimization in the management of projects (e.g., through the targeted use of digital methods and technologies in project management) and through digital platform-based collaboration between stakeholders in building planning and production system planning in the early design and decision-making phases of engineering. This is where the research project "Holistically plan, build, and operate factories with Building Information Modeling (FaBIM)" comes in. The article presents an IT architecture concept based on a design reference process developed in the research project by experts from construction and factory planning. This supports integrated production system and building planning. The concrete application of an integrated BIM-driven data environment approach along the design reference process is demonstrated using the example of a battery cell factory and platform technology from CONTACT Software.

Keywords: Type your keywords here, separated by semicolons ;

1. Motivation

Driven by the fact that around two thirds of factory construction projects miss their cost targets by just under a tenth [1], which means around 330 million for the German market alone [1,2], approaches such as Building Information Modeling (BIM) and digital factory planning have a promising role to play as a key to counteracting this. In particular, the reduction of parallel planning processes and early synchronization of building and factory planning is a promising key to being able to implement projects efficiently and cost-effectively. BIM as a method, historically from the construction sector, also offers some functionalities and added value for factory planning. On the other hand, comprehensive lifecycle approaches (like Product Lifecycle Management (PLM)), as the name suggests, are originally used for classic product data or product lifecycle data and have long been established in industry to manage data and information across generations.

However, holistic approaches from BIM and PLM are not yet established, which is due on the one hand to the fact that the focus of the respective applications is very divergent and on the other hand to the fact that the integrative effort involved with the large number of stakeholders also represents a major challenge for the corresponding IT technical implementation. This is precisely where the FaBIM project comes in. FaBIM stands for "Holistically plan, build, and operate factories with Building Information Modeling". The following contribution addresses the barriers between factory planning and building planning with the targeted use of established PLM methods and tools and is funded on an IT architecture concept based on a design reference process developed in the research project by experts from construction and factory planning.

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2. State of the art

2.1. Building Information Modeling

According to the guideline VDI 2552 of the Association of German Engineers the term Building Information Modeling (BIM) is defined as “methodology for the planning, execution and operation of structures with a collaborative approach based on a digital building information model for joint use” [3]. Thereby, the focus should be on the digital building model, which is intended both to support the working method and to serve the management of information (e.g. time, costs, usage data) [3].Even if in the external representation and perception with the digital building information model often the geometrical 3D model is associated and/or equated, the actual intention lies however more on the term information model, which brings together and interlaces all information along the life cycle of a building and thus in the best case a continuity and synchronization between building data and process information makes possible.

Accordingly, the BIM methodology distinguishes between different degrees of sophistication, which are accompanied by different operational advantages, but also challenges. These so-called BIM levels were first defined by the British government in 2011 to communicate the targeted development stages for digitization of the construction industry and then served as the basis for the "BIM Maturity Levels" defined in BSI PAS 1192-2:2013 [4] [5]. With increasing maturity, the data quality, the data exchange and thus also the coordination of the cooperation of all participants improves. Figure 1 illustrates the BIM maturity levels based on Bew and Richards [7].

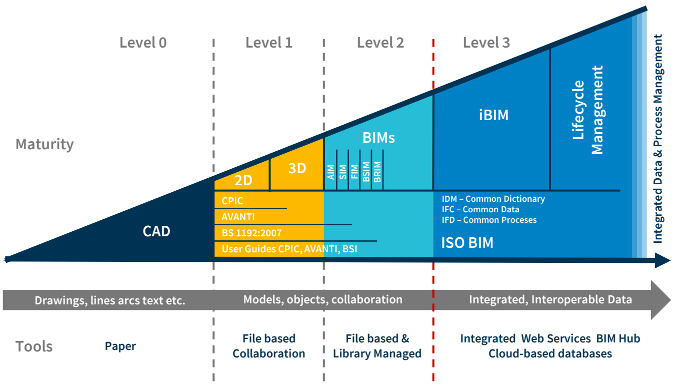

Fig.1: BIM Maturity Level (own representation based on [7])

The Common Data Environment (CDE) plays a key role in this process. The CDE is described as an Internet-based platform for the management of processes and information in all lifecycle phases of a building and is thus the central storage and reference point for all project-relevant information, in that redundancies are avoided, processing is coordinated, data is always available, and information can be exchanged via structured interfaces (in accordance with [6]) [5]. While current standards (also [5]) and national BIM strategies of many countries consider BIM level 2 as the current or next level of maturity and thus rely on a container based CDE, BIM level 3 requires that all information and processes are stored in database structures which would allow to link model elements with documents or even process phases and tasks [5].

2.2. BIM in Factory Planning

In addition to its classical origins in the construction industry, BIM has increasingly found its way into the planning of factories and production environments to master the complexity of current factory planning projects and to ensure digital transparency on the basis of object-based modeling in order to be able to meet the constantly increasing demands on factory planning [3] [8].

Especially in the early phases, factory planning projects are characterized by the fact that the overarching concept is created as a collection of information in different media and several models are only later merged, detailed, and planned out [3] [9]. BIM can help to synchronize planning steps and create a clear design of the factory with central and holistic data management at an early stage, thus maximizing the organizational quality as well as the planning quality in factory planning [3] [10] [11]. High data availability, consistency and transparency are the keys to success to make appropriate decisions in factory planning at an early stage, and to achieve the set factory goals [3]. For this purpose, the BIM model could provide a possible starting point in the factory context [3] [12] by synchronizing, networking, and managing both the corresponding process data and the corresponding object data in terms of building and production environment.

Many academic approaches such as Neuhäuser et. al [13] [14] already discuss the integration of BIM into factory design, whereby most approaches focusing on the technical quality of the model and the resulting organizational quality of the factory design process [6]. In addition, common process procedures in the construction industry such as the HOAI (Fee Structure for Architects and Engineers) applicable in Germany and phases of factory planning are synchronized by corresponding standards such as VDI 5200 (see Figure 2) [15] and extended regarding the application of BIM [16]. However, there is a lack of corresponding tools to manage process and object data in a central storage location in the sense of a CDE in BIM maturity level 3.

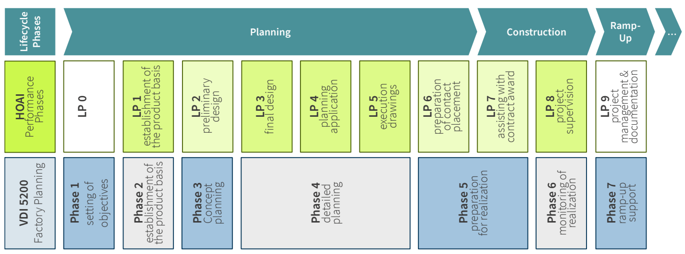

Fig.2: Assignment of the HOIA and the VDI 5200 Phases (own representation based on [15])

2.3. Product Lifecycle Management and Engineering IT-Infrastructure

Originated from Product Data Management (PDM), Product Lifecycle Management (PLM) represents a central concept for the management and provision of product-related information between enterprises, their suppliers, and customers along the entire product lifecycle, to increase the effectiveness and efficiency of related process within a value-chain [18] [19]. To archive these benefits, it is necessary to manage the process and data flows and to integrate the corresponding IT-tools throughout all phases of the product lifecycle. Consequently, the implementation of a holistic PLM solution cannot consist of a single monolithic IT system but is rather based on a number of well-coordinated and integrated IT systems [17] [18] [19].

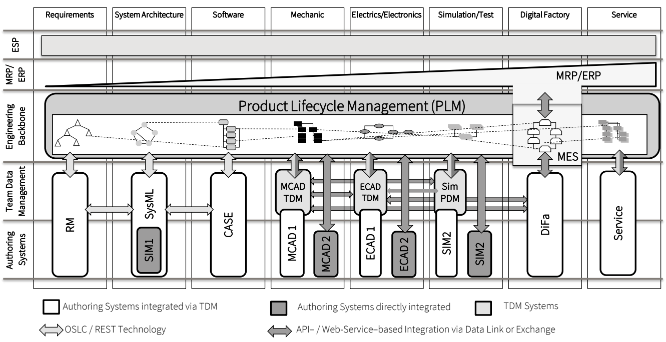

Fig.3: Engineering IT-Infrastructure (own representation based on [17][19])

Figure 3 represents a typical architecture and well-known representation of an IT-Infrastructure in engineering, that cover several layers. The heart of this IT-Infrastructure is the middle layer, the so-called engineering or PLM-Backbone. It helps to administer and harmonize the entire data of the lifecycle by integration the IT-tools of the lower layers on the one hand, which are necessary for the creation and modification of product data and their tool-dependent aggregation and management. On the other hand, it transfers the essential information to the downstream processes of production and product usage and the associated enterprise IT. [17] [18] [19]

3. Common Data Environment Implementation Concept

Both PLM and BIM describe a holistic approach based on a digital information model to manage the object of interest and all associated data and processes along its entire lifecycle, thus improving the collaboration of the participants involved and exploiting the associated benefits. Unlike in construction, digitization in engineering is already more advanced and current solutions thus already enable better, if not yet perfect, data continuity and traceability. Accordingly, this research within the FaBIM project claims to transfer the concepts of engineering to the construction industry, specifically to the planning, building and operation of factory buildings, and in doing so also to build on the concepts and functions of common data management systems to transfer a CDE required for the construction industry to the maturity level BIM Level 3.

For implementing the vision of a BIM Level 3 CDE for the targeted support of factory planning aspects, several experts identified and evaluated cluster requirements in the FaBIM project to understand the various life cycle phases within building and factory development. The initial focus was on the clusters of coordination of construction projects, coordination of factory design and digitization of existing buildings to sharpen a common understanding between building and factory planning. Based on the results of the various expert clusters, an integrated process view was developed which includes the various characteristics and subtleties of the life cycle phases of building and factory planning, based on VDI5200 and HOAI. Based on the process integration, central methods and IT tools were derived that are used within the processes to be able to carry out an authoring tool-focused analysis of the required IT interfaces within the CDE system boundaries. Central aspects of the tools and methods here were, for example, in the context of digital information objects in project management, scheduling, cost calculation, creation and management of requirements, collision and quality checks, variant management, computer aided design, stakeholder integration and collaboration, etc.

An overview of the methods identified is illustrated in Figure 4 and synchronized with the life cycle phases according to VDI 5200 and HOAI. The large number and heterogeneity of the information objects that exist or are to be integrated and administered poses further challenges for a CDE from an IT-technical perspective in terms of the holistic planning of buildings and factories. Especially in terms of management and distribution within the value chain of the various information objects. However, this is a central task and strength of a PLM backbone (see Figure 3). The focus here is on the linking of documents and processes which, with change and release management, make it possible on the one hand to manage documents under version control and on the other hand to relieve the actors who work with the various documents within the processes in the best possible way with comprehensive workflow management and thus minimize the administrative effort. For the design of both the workflows and the object lifecycles for the respective information objects, a method map was created based on the mapping of HOAI and VDI5200 phases. This contains the relevant tools within the HOAI and VDI5200 phases (e.g., project management, AIA, BAP, issue management, visualization, layout planning, construction diary, progress analyses, collision management, construction logistics, 4D scheduling (incl. project costings), as-built digitization, CDE instantiations, feasibility analyses, variant management, IT object-based communication, etc.) and their input and output in the sense of the required and resulting IT objects. The various methods enabled an IT architecture to be derived, considering the authoring tools used in the various disciplines and businesses (as shown in Figure 4). The data required on the CDE from the individual authoring IT-tools was extracted in this manner and used as the basis for a further definition of the interfaces. In this way, a large amount of data could already be structured and administered in the common data environment. In order to enable different stakeholder views of the data and information, the various roles in the factory and building lifecycle (such as client, project manager, BIM manager, BIM coordination factory, BIM coordination building, object planner, factory planner, layout planner, digitization of existing buildings, external service providers, etc.) were then mapped to the identified and processed methods. This ensures that each role involved can view the CDE accordingly.

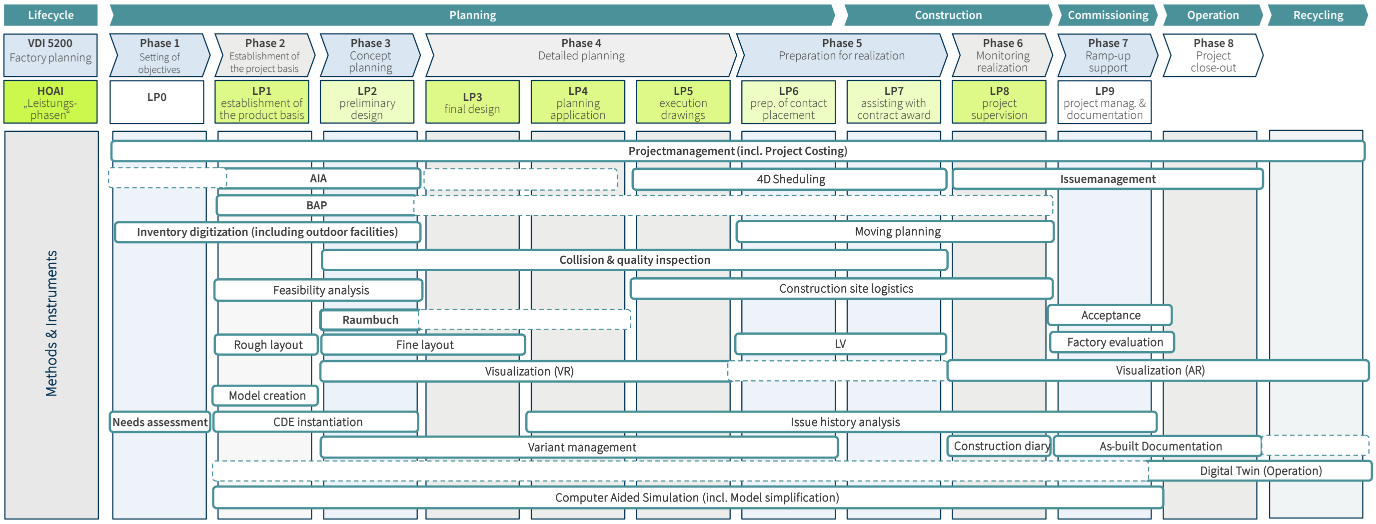

Fig 4: FaBIM-Method Landscape with integrated HOAI and VDI5200 Lifecycle Phases

4. Common Data Environment Use Case Implementation on the example of a Battery Cell Production Site

The use case considered is a fictitious battery cell factory in which pouch cells are manufactured. In battery cells, there are particularly complex interfaces between the production system and the building, which arise from factors such as energy-intensive processes and high requirements for environmental conditions. The associated production process of the battery cell factory consists of seven key steps:

First, a slurry is produced in the mixing process, which is then applied to a carrier film in the coating process and continuously transferred to a drying process. The carrier film is unwound from a coil and then wound back onto a coil. The coated and dried film is then rolled in the calendering process. The wide mother coil is then separated into several smaller daughter coils in the slitting process. The residual moisture is removed in the subsequent vacuum drying process. As the slurry recipes differ between anode and cathode coils, the systems for the production steps up to and including vacuum drying in the battery cell factory are duplicated. The vacuum-dried anode and cathode coils form the central input product for cell assembly. Cell assembly includes the separation and stacking of sheets from the daughter coils, as well as the subsequent electrolyte filling and packaging in the housing. Final cell finalization includes forming (initial charging and discharging of the cell), degassing and aging (quality assurance of the cell properties over a longer period of time) of the battery cell. Therefore, the planning of a battery cell factory is an especially exciting use case for CDE-based collaboration [20]. The annual production volume of this fictitious battery cell factory in three-shift operation is 0.89 GWh, with around three million cells being produced. Within the core processes of factory planning, central methods are shown below as examples within the methods and processes as shown in Figure 4 and organized in the context of CDE implementation. Starting with the requirements for the production system and building, the so-called AIA specification (customer information requirements) is set in the CDE and synchronized with the stakeholders and specialist departments. The AIA is integrated as a template on the CDE, based on the sample of the BIM Deutschland [21] (Center for digitalization in construction) and can thus be instantiated directly for use. A section of the implemented AIA specification is shown in Figure 5 - C and sequentially assigned to the relevant project tasks in the integrated project management as shown in Figure 5 - A. this ensures and tracks consistent synchronization of the delivery objects.

The next step in factory planning, which includes modeling, is concept planning (production system planning) or preliminary planning (construction planning). This step generates a model with a level of detail (LOD) of 100, as shown in Figure 5 – B and E, e.g., a model that includes conceptual geometric objects and general attributes. Rough conceptual collision checks between the conceptual elements are already a part of this planning step. [22] LOD 100 is selected for the machines to implement the use case in the CDE. The initial machines are modeled as 3D volumetric bodies (conceptual objects). Simultaneously, key elements of the factory building such as the floor, walls, and columns are modeled as conceptual objects. These models can be imported as separate IFC files into the CDE where they can be merged and visualized together (Figure 5 – D). The coordination between the stakeholders involved in production system planning and object planning is also actively supported by CDE via various collaboration techniques such as an activity stream (Figure 5 - B). in this way, issues or related conversations can be communicated directly at various information objects (e.g., project tasks, documents, roles, (3D) models etc.) with the relevant roles and objects and efficiently operationalized with the support of an end-to-end integrated project management. This model-based collaboration on the CDE ensures that upon completion of the conceptual planning, a consistent model is available, preventing planning errors from being carried over into subsequent phases. The communication on a specific LOD100 model of the battery cell factory is illustrated in more detail in Figure 5 – B. Furthermore, collision check results can also be imported in the form of BCF (BIM Collaboration Format) [23] files, and the affected elements can be visualized in the model. As part of the associated project management, the activities related to conceptual planning can be assigned to the involved roles and scheduled.

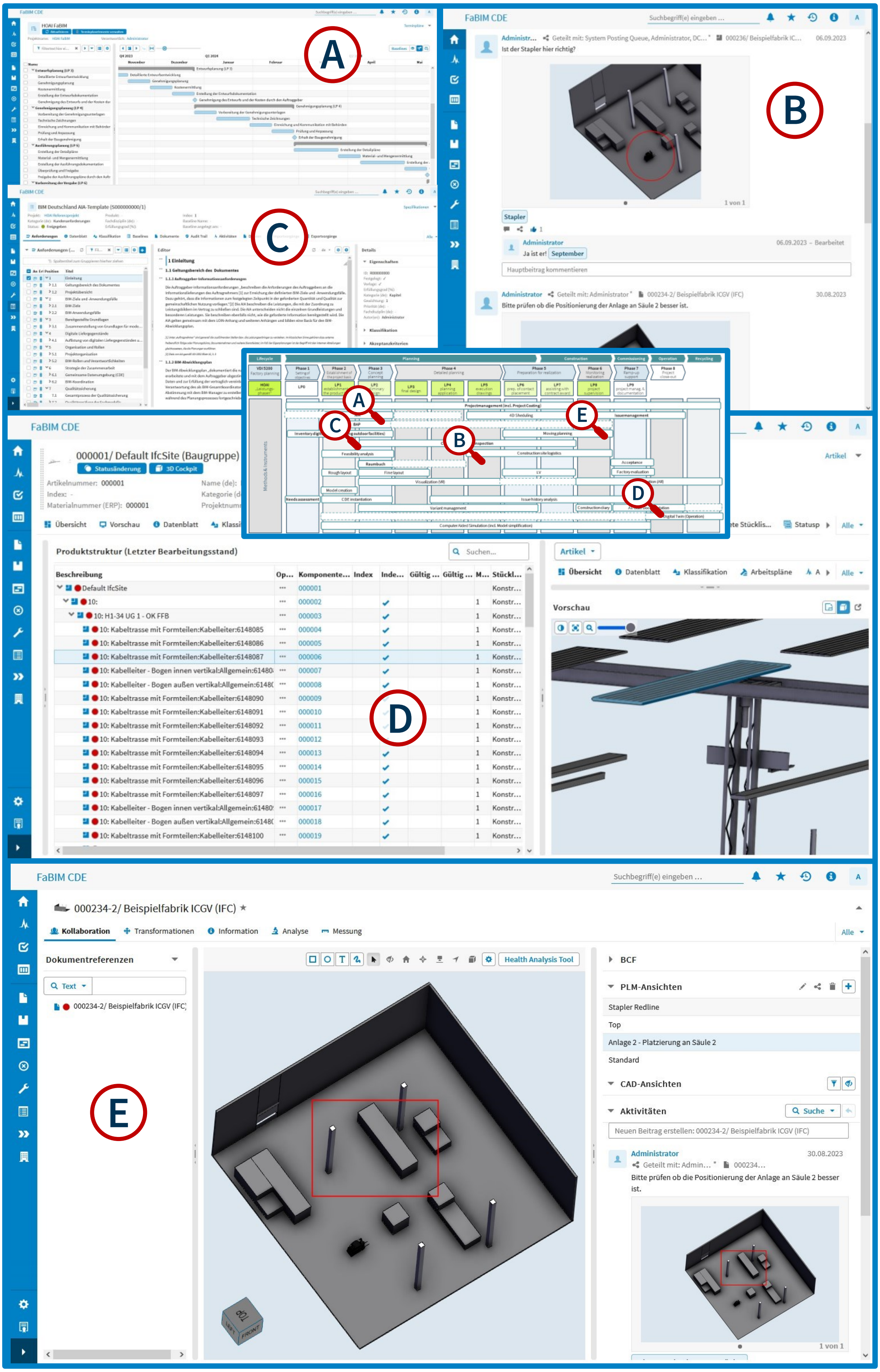

Fig 5: BIM-based Factory Planning Common Data Environment (FaBIM-CDE) Implementation

5. Summary and Outlook

PLM offers great potential supporting BIM projects with comprehensive CDE features. For the holistic planning of factory buildings with BIM, PLM functionalities can generate considerable added value. The methods and IT architectures required for this were discussed in expert workshops in the areas of factory planning, building planning, consulting and IT within the FaBIM research project. Based on this expert knowledge, the required basic IT capabilities were identified and mapped using PLM technologies and expanded in line with the requirements. The so-called common data environment (Level 3) connects the planning of the factory and building and creates a comprehensive digital data and information basis, starting in the early planning and project management life cycle phases, through the building and factory realization to the final commissioning. To this end, a concrete CDE implementation based on the HOAI and VDI5200 lifecycle phases integrated FaBIM method landscape was highlighted using the example of a battery cell factory. In addition to the comprehensive and CDE-centric project management with integrated project costing, collaboration and visualization play an important role. One example here is the IFC format, which can build a bridge between PLM systems and BIM methods within a CDE. With IFC as a model and structure-building format, it is possible to implement PLM-based data management based on BIM building and factory models. This is done with the BOM-based management of IFC components and the subsequent breakdown, identification and management of relevant building components. Through this decomposition, substantial leverage can also be gained from the IFC format for the operating phase, in which relevant model elements of a digital twin can be derived in future (asset BOM) and made manageable by PLM or IoT systems. In future, for example, facility management processes can be developed as early as the planning phase and implemented in the context of the instantiation of the building as a basis for the further planning of service processes directly linked to the respective asset.

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