BIM and AR in Factory Planning: a Combination of Techniques from Architecture, Computer Science and Factory Planning

Sofia Lampe[1] and Julian Böck[2]

[1]Chair of Architectural Informatics, Technical University of München, Arcisstraße 21, 80333 Munich, Germany

[2]Fraunhofer Institute for Casting, Composite and Processing Technology IGCV, Am Technologiezentrum 10, 86159 Augsburg, Germany

E-Mails: sofia.lampe@tum.de, julian.boeck@igcv.fraunhofer.de

Abstract: Companies have to constantly adapt their products to the needs of an increasingly global, rapidly changing market. The production environment needs to change accordingly and factory planning thus becomes a continuous cycle. Plans for existing factory buildings are often not entirely available or outdated. In addition, diverse and incompatible planning tools lead to deficits in collaboration between the planning specialists. These circumstances may cause errors when implementing adaptions. This paper examines how digitalization as well as the use of Building Information Modeling (BIM) and Augmented Reality (AR) can improve the factory planning process by unifying data on the factory building and the production system to grant planners intuitive access to the data. This paper proposes a link-based integration of production data from existing databases into the open-source BIM server to create a single source of truth containing all relevant data for the factory planning process. In addition, we utilize AR to visualize the data on the shop floor for easy and intuitive access.

Keywords: Building Information Modeling, Augmented Reality, Factory Planning

1 Introduction

Today, manufacturing companies compete in an increasingly global and dynamic market [1]. Especially for small to medium-sized enterprises, this can be challenging because new product iterations are required in shorter time spans [2]. To adapt to these shorter product lifecycles and still produce efficiently, manufacturing companies have to optimize their production facilities frequently [3]. Consequently, the factory planning process transforms into a continuous cycle instead of a one-time task [4].

Optimizing existing facilities is considered brownfield planning. Plans of the factory building are often scarce, outdated and only available in 2D. Planning tools are as diverse as the domains of the participating specialist planners. Fuzzy planning data may lead to errors and delays when realizing projects [5]. In order to structure the required data, Building Information Modeling (BIM) offers promising potentials. As an increasingly widespread methodology in architectural building planning, BIM coordinates the different domains and includes centralized data storage based on 3D models. [6]. BIM is not yet commonly used in factory planning, and therefore few factory planning tools support BIM formats.

In the ongoing research project ARBIM4Factory, we examined if a combination of techniques from architecture, computer science and factory planning can be utilized to improve the continuous factory planning process. This paper presents an approach to unifying factory building data and data from the production system using BIM. We propose a link-based integration of production data into an open-source BIM server to create a single source of truth containing all relevant data for the factory planning process. The main goal is to enable collaborative planning of the building and the production system. This collaborative approach ensures that planning errors can be identified earlier. Additionally, we explore possible use cases for AR to help visualize specific information stored within the BIM model to better leverage the model's advantage in the factory's operational phase.

2 Challenges in the Current Factory Planning Process

The factory planning process is composed of two main domains, the production system and the building planning. While the planning of the production system focuses on the value creation in the factory, the building planning forms the envelope. Following classical planning procedures as described in the VDI guideline 5200 1, the processes of both domains run in parallel [7], [8]. This causes problems such as poor synchronization and communication as well as a lack of early collision detection [9], often resulting in schedule delays or costly reconstruction efforts shortly after project completion. Using the methodology of BIM could help to overcome these problems by creating a collaborative planning procedure with consistent and up-to-date data [7], [10]. However, only a few factory planning projects with BIM are known so far.

In factory planning the most common planning cases are development planning and replanning. In development planning projects, a factory is built on a greenfield site, whereas in replanning projects the factory already exists. The so-called brownfield projects are the most common planning cases and the restrictions of the existing facilities must be taken into account, which poses a special challenge. [8], [11]

In most brownfield projects the available planning data is very limited. There are many different data sources, e.g. plans and software systems, which are often not consistent, complete and up-to-date. Since the building and production system are often planned individually, even existing BIM models do not include models of the production system. Therefore one of the first steps is always to digitize the entire factory and prepare the data in a structured way. If this preparation is carried out directly in a BIM model for the production system and building, the data and information can be presented transparently for every planner. This leads to a so-called single source of truth. To alleviate the described problems, we combine techniques from the fields of architecture, computer science and factory planning. We hypothesize that the consistent use of BIM and AR facilitates a faster, more collaborative process by providing each planning expert easy access to the information needed for their specific domain. Thus, experts can communicate and collaborate more effectively.

3 Centralised Data Storage using BIM

The goal is to create a system where all the information relevant to the factory planning process is stored centrally. The data on the building and the production system are pulled together from various sources and consolidated in a single source of truth by either entering it directly into the BIM model or by linking the data from external sources. Traditionally, data of different planning departments is stored decentralized and often analog. When collaborating for projects this often leads to data loss and errors resulting in additional work through the re-entering of data [6]. When using a single source of truth instead, every planner is provided with up-to-date data on the facility and thus changes to the building and the production system can be planned collaboratively.

The benefits of BIM include the continuous use and maintenance of digital data throughout the planning process and the lifecycle of a building. Open data standards simplify collaboration as well as data exchange between teams and enable model checking for planning errors and inconsistencies. A high-quality BIM model can also provide the basis for data-based applications such as simulations [6], [12]. These aspects can be applied to solve factory planning issues as well.

If no models are available, a digital representation of the factory needs to be created in the first step. This can be done by laser scanning the factory and subsequently modelling the building and the production system based on the resulting point cloud. BIM models unify geometric information with alphanumeric data. The resulting geometric models are thus combined with alphanumeric information from existing plans and data lists. A BIM server stores the models and allows remote access to them.

In the case of factory planning, the model must also contain data from the production environment. Existing databases such as Manufacturing Execution Systems (MES) already contain a large quantity of data on the production system such as live sensor data. Many manufacturing companies are using some form of these tools. To harness these data pools, we propose to utilize a prototypical broker where users can set up links between these systems and a database on the BIM server. The broker synchronizes between the database and data sources at regular intervals.

Linking information from the database ensures that the model files do not become too large and thus slow down the server, which can occur when data is entered directly into the model. Automating this data integration eliminates the risk of input errors by humans and guarantees that the various databases stay consistent.

After digitalizing two of our partners' factories, we populated the resulting BIM models with the needed data to realize the most relevant use cases. We used the open-source BIM server by the BIM collective [13] in our research project, as it allows for extension via its Application Programming Interface (API). An overview of the system setup can be seen in Figure 1.

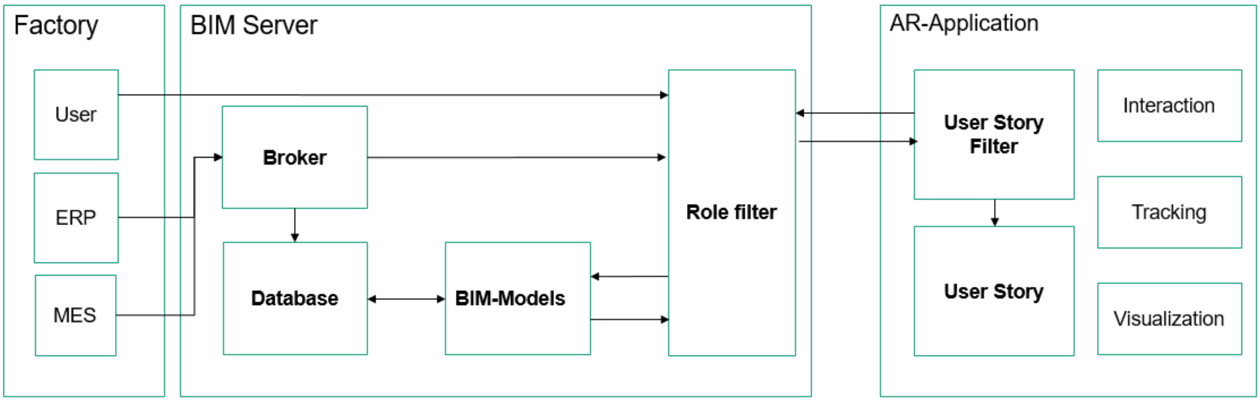

Figure 1: Ideal system uniting databases from the factory, BIM building data and a representation via an AR application.

We encountered problems with loading the BIM model into the AR app in real-time, such as a missing interface between BIM server and the game engine Unity. Thus, the BIM models were loaded directly into Unity using the PiXYZ plugin, with some of the meta data included in the model as well as the possibility to load them from a database.

4 Augmented Reality for On-Site Data Accessibility

The single source of truth contains or links to the available information on the factory building and the production system. Navigating a large system like this can be challenging when searching for a dataset. To make the information on the factory more accessible and transparent for staff on-site, we utilize AR. Therefore the advantages of BIM can still be leveraged after the planning phase. Overlaying virtual models with reality allows not only for comparison between the two but also to enrich the real facilities with information from their digital representation. AR aims to present information that is directly registered to the physical environment. AR goes beyond mobile computing by bridging the gap between virtual world and real world, both spatially and cognitively. With AR, the digital information appears to become part of the real world, at least in the user's perception [14]. This is often done by rendering digital objects on top of a view of the user's real environment. Azuma [15] defines three characteristics of AR: it combines real and virtual, is interactive in real-time and the content is registered in 3D.

This project aims to display the information contained in the single source of truth using AR, forming the interface between the data system and the user. To implement AR, we first identified the appropriate tracking methodology and then developed visualization concepts for different use cases.

4.1 Augmented Reality in Factory Planning

AR as a visualization technique is quite versatile and can be applied to various use cases. In the case of factory planning, there are a few matters of import. The tracking methods need to work in the factory environment. We found marker-based tracking using QR codes, markerless tracking such as simultaneous localization and mapping (SLAM) and point cloud-based tracking to be suitable for use within the factory. Most alternatives do not provide the necessary level of accuracy or impose technical requirements which lead to high acquisition cost. The user interaction needs to fit the work environment as well. Head-mounted displays (HMDs) such as the HoloLens are controlled via gestures, view direction and voice commands [16], which can be challenging for users but allow for hands-free operation. Contrarily, touch screen interaction is familiar to most users but users need to hold and operate it with their hands.

In factory planning, multiple specialists collaborate to optimize the factory layout. On-site AR visualizations facilitate communication between specialist planners of different domains [17]. The AR visualization needs to be tailored to the user's needs and provides additional role-specific information to these planners, like datasets that vary depending on the user's area of expertise, or pieces of information that require specific levels of security clearance to view.

One of the main goals of this research project is to support collaboration between different specialist planners like architects and production system planners. On-site access to the central data source allows planning teams to work more effectively. We chose a tablet as the end device, as it offers better opportunities for collaboration than an HMD since multiple people can view and use the device simultaneously without having to switch HMDs or connect the devices via networking.

4.2 Prototype Concepts

After determining common problems in the factory planning process, we analyzed user scenarios and defined two basic modules: visualizing alphanumeric data contained in the BIM model and displaying 3D models of machines at their designated locations in the factory. By combining these functionalities, the app supports various scenarios, e.g., highlighting necessary connections for new machines to showing sensor data on existing ones. One of the selected user scenarios is checking if a planned location for a machine fulfills the machine's prerequisites, such as connections for high-voltage current, water or compressed air. The lines often run under the ceiling and connectors are provided on pillars at regular intervals. We use color-coded highlights to visualize which requirements the current location fulfills and where the connections are located. For example, the position of available power connections is visualized by green dots next to the connections. Occupied connections are marked with a red dot (see Figure 2, left). We expand the collision detection to take the production system into account. Clashes in the geometry and the semantic information, such as lack of media supply in the surrounding area, can thus be detected and visualized in the app, alerting the planners to problems in the placement.

Another user scenario is accessing alphanummeric data via the AR app. Using the tracking methods, the machine is identified by, e.g., scanning a QR code on the machine. The app then selects the corresponding 3D model in the BIM model, filters the information based on the user's domain and displays static information and live sensor data (see Figure 2, right).

Figure 2: Concept of an AR visualization showing a machine's required connections (left) and the template to show live sensor data (right).

5 Conclusion

Digitalization offers immense opportunities for manufacturing companies when it comes to factory planning. Unifying factory data and accessing it on-site has the potential to improve the factory planning process to be more collaborative and efficient in terms of cost, time and resources. The next steps in this project are the implementation of the AR application and testing it in practice to evaluate the actual impact on the factory planning process of real manufacturing companies.

However, some companies already incorporate practices such as laser scanning and subsequent modelling into their planning procedure, but the usage of the resulting models has to be extended over the entire building lifecycle to exploit their full potential. Since the operational phase accounts for the majority of the life cycle, one model can be used as the basis for all planning measures and facility management during this phase. The biggest challenges are the constant adaptions to the factory and the continuous updating of the BIM model, which is often neglected, leaving the models outdated. Information on the production system is often updated automatically, there are however properties that are not observed by sensors, such as repositioning of machines, which have to be recorded manually and repeatedly in the BIM model. Further research is needed to find ways to simplify or, at best, automate the updating process for these properties.

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