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ScienceDirect

Procedia Manufacturing 45 (2020) 25–30

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

10th Conference on Learning Factories, CLF2020

Requirements Engineering for Stakeholders of Factory Conversion: LoD Visualization of a Research Factory via AR Application

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Abstract

Restructuring in factories is becoming increasingly important to maintain the competitiveness of a factory. In the planning and construction of a factory building, many different project participants turn a construction project into a highly complex task. In the research factory Arena2036 of the University of Stuttgart, in addition to the original research areas of the mobility of the future the building itself is also regarded as an object of research. A method is proposed that uses elements of requirements engineering and enables the user to make a structured decision about the type of a digital building model and its LoD. Requirement templates enable a quick identification of requirements of all stakeholders. The method is suggested to find out which information is important for the stakeholders and what type of digital building model, in which LoD is required for the conversion. Based on this an Augmented Reality application is developed to support the exchange of technical planners during a factory restructuring. The exchange between technical planners is to be streamlined by the application and planning phases shortened. The experiences of using the application are presented and it is proposed as a first step towards a didactic concept in the Arena2036.

Keywords: Augmented Reality; Factory planning; Research factory

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10.1016/j.promfg.2020.04.036

1. Introduction

Factory planning describes the systematic process for planning factories, structured in successive phases. Tools and methods are applied in factory planning to support the complex planning process. The planning of the factory building can be derived from the production task. The demands placed on factory planning and the building in question have changed in recent years, and restructuring is becoming increasingly important [1–3]. Restrictions regarding property, shorter lifecycles of product and production technology, as well as a turbulent environment cause more frequently occurring reconstruction measures within a factory [4]. But conversion in a factory is a complex and resource-intensive process. Digital building models can be employed to support conversion measures in factories. There are different levels of digital building models regarding the information they contain. In general, a distinction can be made between point clouds and building information models (BIM). BIM offers advantages in terms of data quality and availability of up-to-date data. BIM also improves the exchange of information between planners and enables information to be provided on the entire life cycle of a building [5]. The mentioned advantages of BIM can only leveraged if the level of detail (LoD) of the BIMForum of LoD 100 – Lo D500 are used properly [6]. In order to be able to decide which digital building model and which LoD is necessary for the conversion, a method is required to record the requirements for the digital building model and to derive the corresponding required digital building model from this. Essential questions to be answered before a digital building model can be used for information flow and visualization: Which objects or information associated, for which person of information need , should be developed in which exchange form at what project milestone [7]?

Checking the literature dealing with these issues, national standards should be mentioned first. DIN EN ISO 19650 Sheet 1 proposes digital building models to support conversion measures [8]. Although DIN EN ISO 19650-2 addresses the information requirements of the information requestor in the planning and construction phase, only BIM models are considered and no method is provided which supports the selection of the type of a digital building model and its LoD [9]. Grytting et al. developed a method how creative design processes can be structured by the concept of LoD [10]. The building design phases are followed in a LoD decision plan. Short-term information requirements as required in factory conversion planning are not considered. Point clouds are also not considered in the method. Tolmer et al. propose to describe BIM application in detail using formalisms like requirements engineering [11]. However, the method is adapted to infrastructure projects and therefore not transferable to the specific case of factory conversion. Changing the standardized LoD definitions also counteracts the universality of the method. Mourtzis et al. are applying augmented reality (AR) in product design in a teaching factory setting [12]. AR is utilized to envision the product design to students and to evaluate the current design. The AR devices are here smart glasses. Although the requirements of product design are mentioned, the approach presented does not focus on the query and visualization of the requirements. The theoretical concept of LoD is described in the literature as beneficial to information production and exchange. The literature review conducted reveals a research gap in the case of conversion in factories. In the case of factory conversions where the building is affected, it must be possible to plan these ad hoc. Therefore, it is necessary to develop a method that allows to quickly retrieve the required model information. This is where the paper comes in to contribute to the current body of knowledge – by providing an efficient query method including LoD specifications for information need during factory conversion.

2. Methodology

As introduced a method is required that queries project participants in a structured way according to requirements. To accomplish this, requirements engineering (RE) from software development is applied. Originally RE covers the determination of the relevant requirements to a software system. The RE can be divided into the phases requirements elicitation, analysis, documentation, verification and management. Principles of plannability, repeatability and methodical procedure are applied [13].

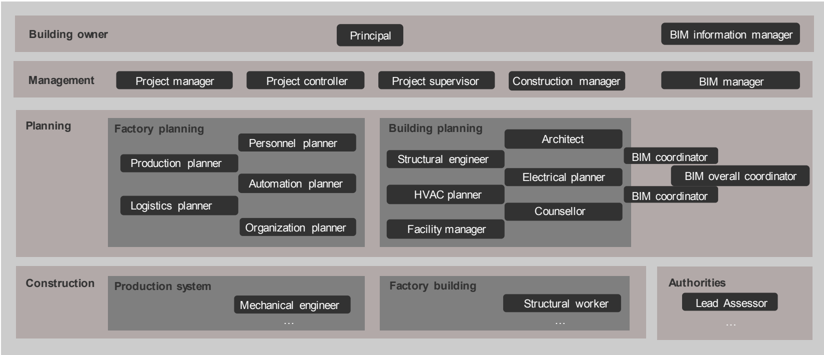

Fig. 1. Participants in the conversion process within a factory.

2.1. Target group

RE is used in the phase of the requirement elicitation with information requirements of the planning participants to a digital building model. The information requirements provide conclusions about the required digital building model and its LOD. In the planning and execution of construction projects, many subdivided project participants [3, 5] with different requirements for a digital building model (see figure 1) are involved. The participants can be divided into building owner, management, planning, construction and authorities. The respective roles of the categories are shown in figure 1. The need of a close integration of factory planners and building planners is emphasized during conversions in a factory [14]. To be able to start planning the conversion, the type of digital building model and the LOD required must be specified. In the following the developed method is presented.

2.2. Decision Point – Type of digital model and Level of Detail

To derive the required digital building model for the reconstruction measure, the planning participants must name the intended object or the information associated, exchange format and date or project milestone when the information is needed. For the structured survey of the intended purpose, an adapted requirements template from requirements engineering is proposed (see figure 2, top). The requirements template was adapted for the identification of a digital building model and its LOD for the conversion phase (cf. figure 2). It is also queried whether the information is necessary or only conditionally needed to create a ranking. After all participants have placed their requirements, due to the systematic query, the requirements can be listed and filtered in the 'Digital Model Information Delivery Specifications' according to urgency, object or information associated, role, exchange format and date (cf. figure 2). An information requestor can make several requests at various times. But the digital building model must contain the information independent of the time. Nevertheless, it is important to determine the timing of the information request, as it is also possible that the LOD will increase in the course of the planning activities [10]. Subsequently, the BIM information manager must determine with the compiled requirements and with the aides of the derivation table (cf. figure 2) the structure of the information. First, the required geometry must be derived. This entails whether a purely symbolic, simplified or detailed geometry is required. According to the required information, a pure solid body of the building, the representation of the outer shell or the detailed geometric components is sufficient. The dimensionality can range from 0D to 3D information. The location information distinguishes between absolute and relative location coordinates. The surfaces of the geometry can be represented symbolically, simplified or realistically. The component geometry can also have complete, partial or no parameterization [15]. The information connected to the geometry can be distinguished into attributes, time information, cost information and contract information, which are linked with the digital building model (see figure 2). This information can be stored in document file formats (IFC, XML, JSON, PDF, DWG, etc.). The derivation table (cf. figure 2) shows that simple information requirements can be provided by point clouds and linked data, especially in LoD 100 and LoD 200. The point clouds represent the geometry much better than the definition of LoD 100 and LoD 200 indicates. However, due to the information that can be stored in a

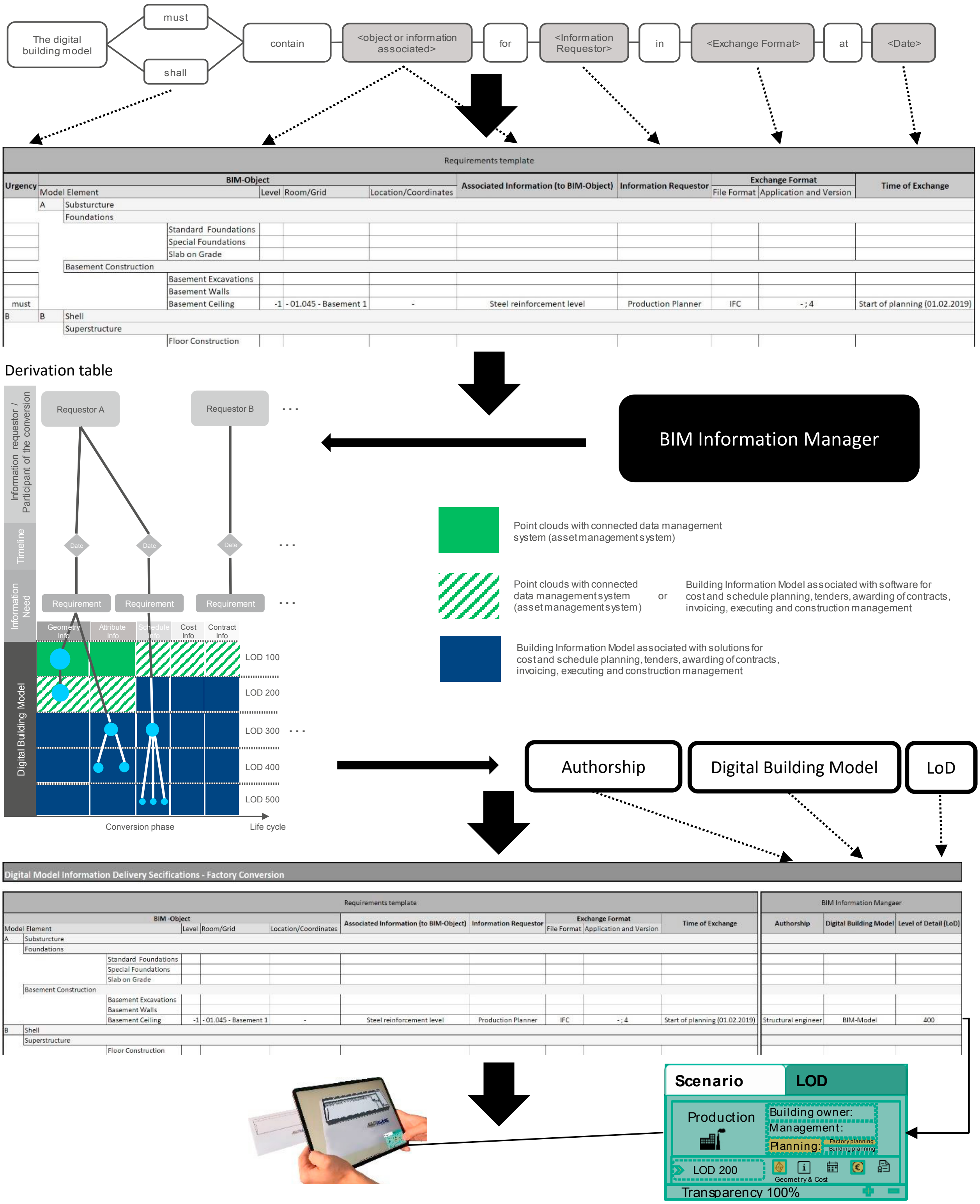

Fig. 2. Overall framework architecture of the method.

data management system linked to the point cloud, they can only be used up to a maximum of LoD 200 from the authors' perspective. BIM models are time-consuming to create. Leite et al. investigated the increased effort required to model higher LoD [16]. Therefore, low LOD is referenced to the fast to create point clouds. In the higher LOD, the use of BIM models is recommended. These can provide significant added value combined with solutions for cost planning, scheduling and contract information. The type of the digital building model and the LoD can be derived from the BIM information manager (BIM IM) by the collected data. Reference is made to literature that deals with the definitions of the LoD [6]. The BIM IM also determines the authorship of the information delivery to be provided (cf. figure 2). This results in the 'Digital Model Information Delivery Specification' (see Figure 2), which is based on Hooper's 'BIM Information Delivery Specification' [7]. Once the respective information authors have created their models in the corresponding LoD, they can be presented in an AR application. The LoD is decisive for the AR application because it is plain to stamp a drawing with a 'Preliminary' or 'Tender Document' or 'For Construction' status. In a BIM project it is less clear. Model elements can have different status at particular project stages; whole models are unlikely to ever have one particular status. In this application the LoD parameter can reveal its potential. It enables downstream users to understand the degree of completeness vis-á-vis how much they can rely on the information at object level [17].The method presented enables the early selection of a suitable digital building model for a conversion to be supported. Thus, the creation of the respective building model can be initiated, or an existing digital building model can be used.

3. Use of a BIM model in construction meetings by applying an AR application

Due to this research a point cloud and a BIM model is created of the Arena2036. This data is available and can be used for the AR application. The target group in this case are planning participants from the factory and building planning during reconstruction measures. The corresponding digital building model can then be used for construction meetings by AR applications. In an AR application developed for the application case, the respective role, the LOD and the required geometry can be displayed with either attribute, schedule, cost or contract information. In the present case, the Arena2036 BIM model was created in LOD 200. In addition, information on component attributes and costs is available. The application is designed to display three-dimensional content on a 2D floor plan (see figure 2). This makes it possible to include additional information, which is not visible in the 2D floor plan, in planning discussions on the construction site. In this way, information can be prepared in the application in such a way that it is comprehensibly accessible. The application runs on Android and iOS smartphones and tablets. It was created in Unity using the Vuforia AR engine. Information can be accessed portably and can thus be used as a communication instrument for construction site meetings. During use, it is noticeable that complex geometries, which are difficult to interpret from pure 2D plans, can be made easier to understand by the application. In addition, the selection of different LODs allows the optimal view of the required information. This prevents valuable information from being missed or a flood of information from delaying decisions. However, weaknesses in the application also become apparent. A more detailed selection of objects is required by the users. To realize a fast development, many geometry objects were combined. In retrospect, however, it turned out that more detailed information is often required for small objects.

4. Summary and Outlook

To take up the research gap described in the beginning, the Arena2036 of the University of Stuttgart was chosen as a representative factory environment. Referring to the definition of Learning Factories in the narrower sense, the Arena2036 cannot be regarded as a Learning Factory [18]. No physical products are manufactured, and no didactic concept is pursued. In the present approach, however, the focus of the research is not on the production aspect of the factory but on the building associated with it. The factory building of the Arena2036 provides all the technical prerequisites of a factory and was built as an employable factory for research purposes. Nevertheless, the presented application has the potential to be employed as a didactic element to teach on factory restructuring. It is able to visualize the connections between production and building and make them easier to understand. The concept of the Arena2036 so far is intended to bring science and industry together in a short-term, project-oriented way (knowledge and experience transfer). The Arena2036 incorporates at the moment only two of the three poles of the "knowledge triangle" [19], [20]. The proposed AR application could be a extension towards a didactic concept and thus be seen as a first step towards the 'knowledge triangle'. To be able to react to changes with the building as quickly as production, the interaction between production and the factory building must be researched. In this case, the derivation of a suitable digital building model for conversion processes is examined in focus. The information requirements of all stakeholders involved in the conversion can be recorded in detail with the structured querying of the method. The proposed method uses elements of requirements engineering and enables the user to make a structured decision on the type of digital building model and its LoD. To further test the method, participants from different domains should place their requirements on the digital building model during conversions in the Arena2036. To discover which target group tends to require the highest LOD. It would also be conceivable to use the method in other research factories or learning factories to compare the required LOD of the stakeholders for different buildings and different conversion measures. Not only in research factories, but also in learning factories, the focus should be more on the factory building.

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