# Designing the Procurement Logistics Processes of a Smart Factory based on Virtual Building Models

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**Abstract.** Smart factory research has primarily concentrated on the manufacturing sector, without taking the building sector into closer consideration. Combining these two ventures can lead to a variety of synergies to minimize the $CO_2$ emissions of existing buildings. By producing facade and roof panels on an industrial scale for energetic refurbishments, Construction 4.0 and prefabrication can make a significant contribution to achieving climate targets. In this context, the purpose of this paper is to identify, how data of a virtual building can be used in procurement logistics of a smart factory. To achieve this, this paper follows a case study analysis. At the beginning, the procedure of developing a virtual building model is described. This is followed by the design of the inbound workflows of a smart factory in the construction industry. The findings demonstrate how the information from virtual building models can be leveraged to control procurement processes of a smart factory.

**Keywords:** Virtual Building Models, Smart Factory, Procurement Logistics.

## 1 Introduction

The expected effects of Industry 4.0 on the economy are remarkable. The Organization for Economic Cooperation and Development predicts that the global gross domestic product will almost triple by 2060 [1]. The implementation of smart factories alone could add at least €1.35 trillion in value to the global economy. Currently, most studies focus on the six main industries – machinery and equipment, electrical and electronic equipment, automotive, chemicals, agriculture, and information technology – which are expected to have a value creation potential of €78 billion by 2025 [2].

In comparison, the potential of Industry 4.0 for the construction industry has received relatively little attention. The existing building stock contributes to 40 % of the total energy use and 36 % of the $CO_2$ emissions. The majority of European residential buildings, of which approx. 51 % have been built before 1969, are in high need of renovation. The North Sea region (NSR) alone contains 22 million dwellings which cause 79 Mton $CO_2$ emissions annually. To deal with the climate crisis, climate and energy objectives were defined. By 2050, $CO_2$ emissions should be cut to at least 80 % compared to 1990 and buildings should be energy-neutral [3]. However, the building renovation industry applies mainly manual on-site techniques, resulting in a low renovation pace (ca. 2% p.a.), high labor costs and a long duration [4]. Thus, the ambition to achieve the climate targets is challenging for the sector.

The integration of smart factories could enable growth in the construction industry, as the manufacturing of housing units could take place on an industrial scale. Automated processes create efficient manufacturing approaches in residential renovation to reduce $CO_2$ emissions to a necessary limit [5]. In this context, this paper aims to identify how data generated by 3D models of residential buildings can be used for managing the procurement processes of a smart factory in the construction industry.

## 2 Related work

### 2.1 Impacts of Digitalization on the Construction Industry

In recent years, efforts have been intensified to invest in the digital transformation of the construction industry. Initiatives are being subsumed under the term "Construction 4.0". However, similar to Industry 4.0, there is no consensus on what Construction 4.0 means. Some authors describe it as a manifestation of Industry 4.0 in the construction industry and the use of modern technologies such as the IoT, Big Data, AI or advanced manufacturing, as this could enable a decentralized, cost-effective production in smart factories [6]. A second group considers Construction 4.0 as an opportunity to find complementarities between technological approaches to address the current challenges facing the construction industry [7].

This paper follows the view of the first group of authors that industrialization in construction can lead to the implementation of smart factories. Accordingly, this requires a redesign of supply chains, as building material is now processed in factories before being delivered to the construction site, instead of being delivered directly.

### 2.2 Smart Factories in the Construction Industry

A smart factory is defined as the integration of artificial intelligence (AI), mechanical engineering, and information technologies. It can be understood as a flexible production facility of Industry 4.0, based on intelligent units, where machines coordinate production processes independently and autonomous transport vehicles carry out logistical tasks. The involved objects, such as machines, products and/or vehicles, exchange information autonomously in real-time via the internet [8]. The Internet of Things (IoT) is used to integrate resources, allowing the manufacturing system to have sensing, connecting and data integration capabilities. In this context, data is the most important basis for a smart factory. It is used in all areas, from the initial design of the products, through procurement to manufacturing [9]. This enables a dynamic production structure where processes are no longer statically predetermined, but adjusted based on the individual customer order. A flexible manufacturing system is created, which utilizes a continuous stream of data from connected systems to learn and adapt to new requirements [10].

In regard to the future of the construction industry, entire house units can also be autonomously prefabricated in factories. These Smart Construction Factories aim for more standardized, cost-effective, and faster production compared to on-site construction processes. The labor costs of the construction sites are consequently converted into capital costs. In addition to new buildings, the market for refurbishment can also be addressed, as these factories can produce serial renovation packages. They consist of facade and roof panels, solar collectors and heating, ventilation, air conditioning (HVAC) systems.

### 2.3 Virtual Building Models

The building sector adopted in the past innovations for design such as 3D drawing and Building Information Models (BIM), which allow to seamlessly integrate different engineering disciplines, to have a closer look on construction details and material use as well as to realize a higher construction quality. To further automate the procurement and production processes, more information is needed and thus more detailed models of the products are required. Therefore, high-resolution models can be used. The data level of detail of these models extends BIM. High-resolution models and BIM both contain the same data such as 3D geometrics, material or components use and installations. However, high-resolution models also contain additional data of (hygro-)thermal bridges, air flow paths, air leakage and operational schedules for e.g. lighting and occupancy, HVAC and domestic hot water systems as well as embedded renewable energy systems [11]. Using this data, a comprehensive virtual model of the building and its performance is generated, paving the way for subsequent mass production.

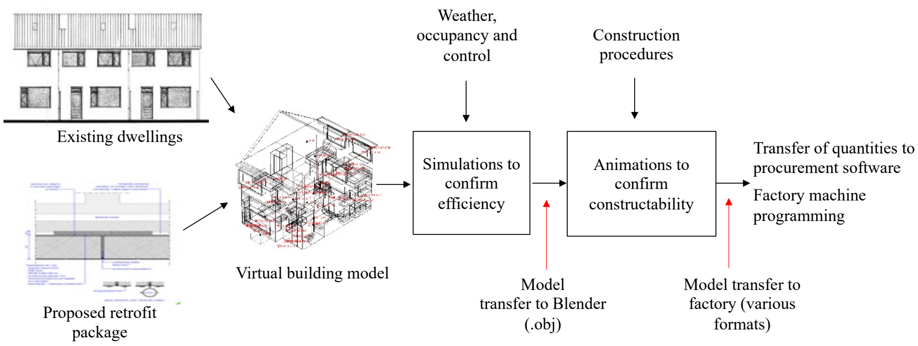


**Fig. 1.** Construction processes based on high-resolution building models [9].

High-resolution models can help to simulate all properties of the building, such as the condition following an energic refurbishment in which the building is renovated with panels from the Smart Construction Factory. The virtual model consists of the data of the existing building and the new facade and roof panels. Within the model, energy calculations and assembly simulations can be performed (in Blender) to verify the retrofit achieves the desired standard. If it passes, the .obj-file formats can be forwarded to the smart factory and be transformed to other machine language protocols to initiate production and logistics processes, such as procurement logistics (see Fig. 1) [12].

## 3 Methodology

This contribution focuses on describing and analyzing a case-study. Case study-based research distinguishes between a descriptive analysis, in which correlations are described, and an explicative analysis, in which correlations are additionally examined with respect to their variability [13].

As this contribution emphases on the identification of the influence of virtual building models on procurement processes of a smart construction factory, a descriptive case study methodology according to [14] is applied. Here, five components of a research design are important:

1. The research question,
2. Its propositions,
3. The unit of analysis,
4. The logic linking of the data to the propositions,
5. The criteria for interpreting the finding.

Following the five components, this study focuses on the research question, how building data can be used to control procurement processes of a smart factory (1). The assumption is, that the use of virtual building models can increase the efficiency of the procurement processes (2). The case study of this paper is the scientific project INDU-ZERO (3). A virtual building model can increase the costs and the effort involved in the design stage (4). At last, the study needs to verify that the new automated processes can cover the additional effort of creating a high-resolution model (5).

## 4 Application of Virtual Building Models in Procurement Logistics

To tackle the need for energetic renovations, six countries of the NSR collaborate in the Interreg project INDU-ZERO “Industrialization of house renovations toward energy-neutral” with the ambition to upscale the current renovation process and to create the necessary facilities. INDU-ZERO aims to design a smart factory blueprint to produce 15,000 fully integrated prefabricated renovation packages per year per factory suitable for all NSR countries at a reduced cost of 50 % [4,15].

In the INDU-ZERO project, a high-resolution model was generated as a 3D representation of one building to be refurbished after it was scanned. Based on the measurement points and using specifications, it was developed into a digital design that includes a structured hierarchy of product information and associated naming criteria, tabular metadata and a common organization via databases.

Procurement logistics comprises the connection between the supplier's distribution and the manufacturer's production. Its objects are raw materials, supplies and merchandises that have to be made available to the manufacturer. Correspondingly, it is the function of procurement to provide, maintain and develop delivery capacities.

To provide coherent instructions for the procurement processes of the Smart Construction Factory, the manufacturing data describing the product parameters had to be converted into readable data sets for the product lifecycle management (PLM) system.

Material requirements such as material quantities, design and insulation specification were generated in the PLM system. For each construction order, the combined design and PLM data was in turn queried by the Enterprise Resource Planning (ERP) system and ordered from suppliers according to the pull principle (see Fig. 2).

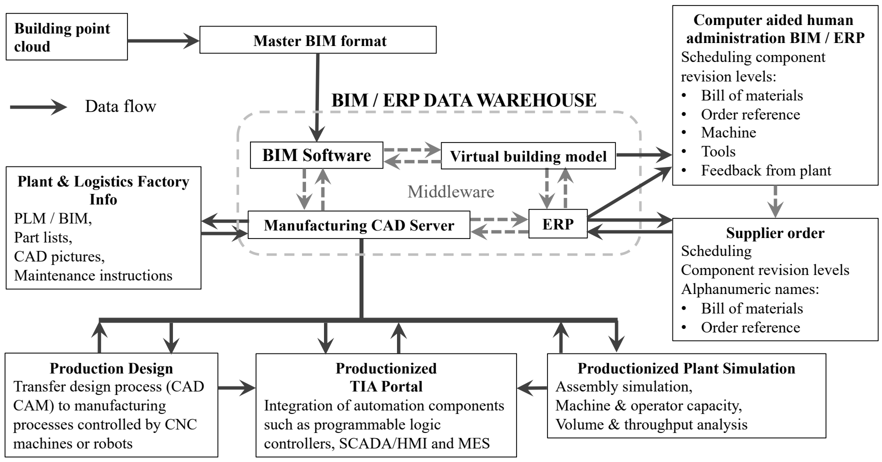


**Fig. 2.** Design of the information flows in a Smart Construction Factory.

In the implementation phase of the case study, an enterprise service bus (ESB) was used as a middleware for the data transfer between the systems. It was able to forward the data from the high-resolution model to the PLM and ERP system. After receiving the data of the materials, the suppliers prepared the transportation. Regarding the purchase, suppliers referred to predefined agreements so that individual orders do not have to be renegotiated. With this scenario, analogue administrative processes between the procurement, production and sales departments were avoided.

Furthermore, it was not only possible to benefit the procurement logistics processes from the virtual building model, but also to use its data to design the product and simulate the production processes of the smart factory and thus test their success.

## 5 Discussion and Results

The case study shows how high-resolution building models can be used for the procurement logistics of a smart factory in the construction industry. This applies in particular to the supplier ordering process of materials by transferring the BIM data to the PLM system and then to the ERP system with the help of an ESB middleware.

From a logistical point of view, the process changes that resulted in the case study have the most impact on the accuracy of purchase orders, the rate of emergency purchases and purchasing time. Automated purchase orders and predefined master agreements not only shorten order times, but also allow the immediate release of order quantities from actual materials used. Supplier availability, fulfillment rates, and invoice accuracy from contracted details are also met, ensuring that there should be no bottlenecks as suppliers commit to fixed quantities at specific prices and times.

From a manufacturing point of view, the most valuable components of the new information flows between the systems are algorithmic and parametric product designs. They describe the geometry of all individual parts that compose the bill of materials for the facade and roof panels, which can then be used by the PLM and ERP system to comprehend the design context and automate production and logistics processes.

Thus, the assumption made in the methodology that efficiency gains are possible is confirmed. By creating uniform interfaces in the software system landscape in advance, procurement and production processes can be automatically adapted to the building structures in the future without increasing the workload during operation.

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