MITIGATING PRODUCT DATA MANAGEMENT CHALLENGES IN THE WOODEN SINGLE-FAMILY HOUSE INDUSTRY

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SUMMARY*: The housing industry faces challenges in product data management, resulting in negative effects on productivity, efficiency, and quality. The purpose of the study presented in this paper is to elaborate on requirements and functions of a support system to mitigate challenges with product data management in the wooden single-family house industry. As a support system, a pilot product lifecycle management (PLM) system was developed with functions to fulfill the requirements. The support system was installed and tested in a real-world setting, a wooden single-family house company, Company T. The paper contributes with the insights that a PLM system for industrialized house building can be developed, fulfilling the requirements in this specific industry. The functions developed were perceived to have value and could, for Company T, mitigate their challenges with product data management. The support system facilitate integration between the pilot PLM system, the building information modeling tool and the enterprise resource planning system at Company T. Based on the study carried out, the paper concludes that a PLM system is feasible, and that it might be a way to mitigate challenges with product data management in the wooden single-family house industry.*

KEYWORDS*: product lifecycle management, building information modelling, product data management, industrialized house building, design research methodology, support system, system integration, interoperability*

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1. INTRODUCTION

The construction industry and especially the housing industry is struggling with challenges related to product data management which have negative effects on productivity, efficiency, and quality (Halttula et al., 2020; Jensen et al., 2008). In this paper, focus is on the wooden single-family house industry, a segment of the construction industry utilizing industrialized house building (IHB). IHB has characteristics of both traditional on-site construction and the discrete manufacturing industry. Unlike traditional on-site construction that has a project-oriented strategy, IHB engages in off-site manufacturing and higher vertical integration of value chains, employing a combination of a project-oriented strategy and a product- and process-based strategy (Lessing et al., 2015; Vestin et al., 2022). IHB has a distinctive advantage compared to the traditional construction industry—it owns or has greater control over significant portions of the value chain. Unlike the conventional construction sector, where various entities often handle different aspects of a project, IHB takes a more comprehensive approach. This means that IHB companies may manage activities ranging from design and manufacturing to assembly and delivery, giving them greater influence and control over the entire product realization process (Popovic, 2020). From here on, the term IHB will be used to denominate the focused section of the wooden single-family house industry.

In terms of product data management, a common challenge for IHB is a lack of systems integration between information and communication technology tools (ICT tools) i.e., product data exists in isolated systems (Lennartsson et al., 2020; Popovic et al., 2019). System integration implies integration of existing, often different, systems. Focus may be on increasing value to the customer through for example improved product quality and performance, while at the same time providing value to the company through reduced operational costs and improved response time (Mische, 2002; Vonderembse et al., 1997). In IHB, the lack of systems integration is causing unnecessarily repetitive processes for organizing and navigating between different ICT tools (Vestin & Heikkinen, 2022). It can be difficult to find the right product data, especially for new employees, since unique product data can be stored at separate locations and be accessed with different ICT tools (Halttula et al., 2020; Jensen et al., 2008; Vestin & Heikkinen, 2022; Vestin et al., 2022). Another challenge is that the product data in the different ICT tools lack revision management, which means that even when product data is found there is uncertainty whether it is the most recent data (Halttula et al., 2020; Jensen et al., 2008; Vestin & Heikkinen, 2022; Vestin et al., 2022). Tacit knowledge is needed to navigate between the different ICT tools, both to procure data and to add data related to the product (Vestin et al., 2022). For example, purchasing of parts like joists, insulation, etc. is particularly challenging due to the lack of integration between building information modelling (BIM) tool and enterprise resource planning (ERP) systems. Usually, a BIM model is searched for all purchasing items which is extracted to spreadsheets and after that the retrieved product data is rewritten into an ERP-system (Lennartsson et al., 2020; Vestin et al., 2022). The challenges related to product data management have negative effects on productivity, efficiency and quality. For example, issues with input of product data and tedious and time-consuming administration (Lennartsson et al., 2023; Lennartsson et al., 2020; Malmgren, 2014; Persson et al., 2009; Popovic et al., 2019; Vestin et al., 2021).

Several attempts have been made to mitigate the product data management challenges in IHB. In this paper, ´product data´ refers to data and information about the product that are of value for the product realization process. Data refers to an unorganized fact that needs to be processed to make it meaningful. Information refers to data about the product that is processed, organized, and structured (Davenport & Prusak, 1998). Product data can be located and represented in different ICT tools but also in human minds. ICT tools refers to tools used for accessing, gathering, manipulating, presenting or communicating information (Zuppo, 2012). The ICT tools could include hardware like computers and other devices, software applications, and connectivity such as access to the internet and local networking infrastructure (Zuppo, 2012). Product data management refers to handling of the data/information in and between ICT tools throughout the product realization process.

Previous research suggests that IHB should support the product and process strategy, more often seen in the discrete manufacturing industries, using ICT tools with functions to manage product data efficiently (Johnsson et al., 2006; Lennartsson et al., 2023; Lennartsson et al., 2020; Malmgren, 2014). IHB is using ICT tools for product data management, such as BIM, which is developed for the traditional construction industry (Johnsson et al., 2007; Johnsson et al., 2006). Hence, it is a source of the product data management challenges found in IHB (Gharaibeh et al., 2022; Santos et al., 2017; Turk, 2020). Furthermore, a trend has been recognized where BIM-tools have been expanded with plug-ins to better suit the needs of IHB (Yin et al., 2019), indicating that BIM-tools are lacking functions for product data management for IHB (Gharaibeh et al., 2022; Turk, 2020). Nevertheless, a recent study on digital technologies in offsite and prefabricated construction emphasizes future digital technology development should build upon existing BIM tools to enhance their capabilities (Cheng et al., 2023).

Moreover, attention has been on adopting ICT tools with different capabilities, such as ERP-systems (Babič et al., 2010) and Product Lifecycle Management (PLM) systems (Aram & Eastman, 2013; Biccari et al., 2018; Holzer, 2014; Lennartsson et al., 2023; Mangialardi et al., 2017). A recent study in a Swedish company producing prefabricated school buildings suggested that typical functions of a PLM-system could be a possible solution to mitigate product data management challenges in IHB (Lennartsson et al., 2023). Expected challenges with this type of system solution included the integration of a PLM-system with computer-aided design (CAD) software and an ERP-system (Lennartsson et al., 2023). A different approach to mitigate product data management challenges was an effort to create a demonstration tool with the function to generate the bill of materials (BOM) based on BIM data (Mukkavaara et al., 2018). The demonstration tool did not show how to transfer product data between systems, but rather how to describe a house product in a way that facilitates this data transfer.

There is a limit to the current understanding of the intermediate steps from challenges of product data management in IHB and how these challenges can be mitigated, especially when ICT tools are developed as a mitigation strategy. The knowledge gap this paper addresses is what the needed requirements and functions of a support system are, and which ICT tool can be a suitable support system to execute the functions and fulfill the requirements to mitigating product data management challenges in IHB. Due to this, the purpose of this study is to elaborate on requirements and functions of a support system to mitigate challenges with product data management in the wooden single-family house industry. To address the purpose an empirical study was done at a Swedish wooden single-family house company.

The rest of the paper is structured as follows. Initially, the theoretical framework is presented, including the context for the study, i.e., product realization in IHB and ICT tools for product data management. Next, the research methodology is introduced, detailing information about applied research methods and the logic applied for the analysis. After that, the findings are presented. Finally, based on a discussion of the findings, conclusions are drawn and the implications for practice and theory are outlined.

2. THEORETICAL FRAMEWORK

2.1 Product realization process in IHB

IHB engages in off-site manufacturing and higher vertical integration of the value chain, therefore employing a combination of a project-oriented strategy with a process- and product-based strategy during the product realization process (Lessing et al., 2015; Vestin et al., 2022). There will always be a building site with unique characteristics that demands a project-based strategy. The characteristics of the building site need to be considered and can force changes to the process and product, even though IHB strives to have a process strategy. IHB has been defined as "A thoroughly developed building process with a well-suited organization for efficient management, preparation, and control of the included activities, flows, resources and results for which highly developed components are used in order to create maximum customer value" (Lessing, 2006 p. 93). In IHB, the product realization process in general can be divided into six phases, i.e., sales, design, production, transport, assembly and completion see Figure 1.

Figure 1: Product realization process in IHB, adapted from Söderholm (2010).

The design phase is often one of the most time and resource inefficient parts of the product realization process, hence being the bottleneck of the product realization process at most IHB companies in Sweden (Thajudeen et al., 2019). The design phase generates large amounts of product data that concerns the entire product realization process (Persson et al., 2009). Depending on when the house becomes customer specific, the design process can be more or less complex. To various degree, parts of products are predefined, depending on the applied prefabrication strategy. A high prefabrication level implies mainly standard design solutions and a less complex final design phase, whereas a low level of prefabrication implies that the design phase becomes more complex. In addition, the result of the design phase affects the quality of product realization in all subsequent phases and is therefore crucial (Popovic, 2020). To support the design phase in IHB, a platform approach is commonly applied (Jansson et al., 2014; Lessing et al., 2015). Standard predefined parts of the product, such as modular components and elements, are based on building systems, which is the underlying core product technology. The predefined parts form commonality across a product range, and their configuration generates product variants that are differentiated by the market (Jansson, 2013; Popovic, 2020). Predefined parts and building systems are solutions that are developed considering the whole lifecycle of products (Persson et al., 2009).

The formalization of product platform knowledge and its management through ICT tools, specifically product data management, is essential to facilitate the efficient reuse of product platform assets during the design and manufacturing stages of product realization (Eriksson & Emilsson, 2019; Jensen et al., 2012; Malmgren et al., 2011). The product data needs to be managed efficiently through all the product realization phases (Malmgren, 2014). To support this, modern ICT tools can be integrated and manage the product platform in a way that facilitates enhancing value for the customer, such as through increased product quality and performance, while also adding value for the company, for example by reducing operational costs and improving response time (Ekholm & Molnar, 2009; Popovic, 2020). The development of platforms in IHB calls for the use of modern ICT tools as an integrating tool in a new type of house-building process (Ekholm & Molnar, 2009; Popovic, 2020; Popovic et al., 2019).

2.2 ICT tools for product data management

Due to the combined project-, process-, and product-based strategy for the product realization process in IHB, IHB needs ICT tool capabilities that integrate elements from both the construction and discrete manufacturing industries to effectively meet its requirements (Malmgren, 2014). The most common ICT tools for product data management in the house-building industry are BIM-tools, while in discrete manufacturing ICT tools like product data management (PDM) system or PLM-system is used for data management. PLM is described as the activity of managing products effectively across their lifecycle (Stark, 2020).

2.2.1 BIM-tool for product data management

IHB usually utilizes two different CAD/BIM-tools for product data management, one for 2D and one for 3D modeling, the latter usually a BIM-tool (Lennartsson et al., 2020; Popovic et al., 2019). Recent research indicates that BIM-tools, for example BIM, Bentley, and ArchiCAD, are utilized differently in IHB and functions have been developed with plug-ins to better fit the needs of the industry (Yin et al., 2019). In a recent study on wood construction projects in the Swedish context, participants frequently identified barriers related to IT and software in the implementation of BIM (Gharaibeh et al., 2022). Integration challenges were a recurring issue, both between different software systems and among project teams and stakeholders. The use of multiple data formats for information exchange was cited as a cause of data loss and time wastage. Some participants raised concerns about the suitability of BIM for certain disciplines, noting its limitations in performing specific tasks. Specifically, in the context of structural analysis, the study found that some participants criticized the perceived low-quality geometry of industry foundation classes (IFC) and expressed a preference for alternative formats and tools better aligned with their needs (Gharaibeh et al., 2022). Nevertheless, a recent study on digital technologies in offsite and prefabricated construction asserts the indispensable role of BIM tools. The study suggest that BIM tools will play an indispensable role and future digital technology development should be built on the existing BIM tools to expand its capabilities (Cheng et al., 2023).

Product data management is a crucial component within IHB, particularly during the product realization process and the design phase. It plays a vital role in ensuring housing projects are delivered on time and with the desired quality (Mukkavaara et al., 2018). As mentioned in the introduction, the product data usually exists in different ICT tools and manual transfers between ICT tools are required (Mukkavaara et al., 2018). This manual handling of data gives rise to quality issues with input of product data and tedious and time-consuming administration (Lennartsson et al., 2020).

Several attempts have been made to mitigate the product data management challenges in IHB. A demonstration tool using BIM data to generate an engineering view on the BOM was developed to mitigate challenges of managing product data and enabling diverse views on product data (Mukkavaara et al., 2018). The application of BOM in the context of IHB have been suggested as one of the building blocks for linking islands of ICT tools, expected to organize product data for various purposes (Lee et al., 2011). Within the discrete manufacturing industry, BOM is seen as the core of information systems and an essential part in the ICT toolkit (Hegge & Wortmann, 1991). BOM is critical for many information systems, such as material resource planning (MRP), ERP and Product Data Management (PDM) (Jung et al., 2014). BOM is as a collection of materials and components that make up a product, together with their quantities (Chang et al., 1997). BOM can also be a product specification, showing how a product is put together from its immediate components with relationships between components (Hegge & Wortmann, 1991). This insight was adopted in the demonstration tool developed by Mukkavaara et al., (2018). The function generated a BOM that provided a view of a building based on its composition, and how individual modules and walls are composed. However, the demonstration tool did not show how to transfer product data between systems, but rather how to describe a house product in a way that facilitates this data transfer. Future research was suggested on how BOMs could be used to bridge ICT tools in order to support design and production of houses (Mukkavaara et al., 2018). Although it is also argued that BIM-tools are lacking the ability to handle product structures (Biccari et al., 2018; Boton et al., 2016). Product structure is a key function for systems integration (Lee et al., 2011).

Nonetheless, BIM-tools have challenges with product data management (Gharaibeh et al., 2022; Santos et al., 2017; Turk, 2020) and are further developed with plug-ins to better suit the needs of IHB (Yin et al., 2019), indicating that BIM-tools are lacking functionality to facilitate product data management (Gharaibeh et al., 2022; Turk, 2020).

2.2.2 PLM-system for product data management

Development of platforms in IHB calls for use of modern ICT tools as an integrating tool in a new type of house-building process (Ekholm & Molnar, 2009; Popovic, 2020; Popovic et al., 2019). Research indicated that a suitable ICT tool to mitigate challenges with product data management in IHB might be a PLM-system (Aram & Eastman, 2013; Biccari et al., 2018; Boton et al., 2016; Holzer, 2014; Lennartsson et al., 2023; Lennartsson et al., 2020; Mangialardi et al., 2017). PLM has been defined as “A strategic business approach that applies a consistent set of business solutions that support the collaborative creation, management, dissemination, and use of product definition information. Supporting the extended enterprise (customers, design and supply partners, etc.). Spanning from concept to end of life of a product. Integrating people, processes, business systems, and information” (CIMdata).

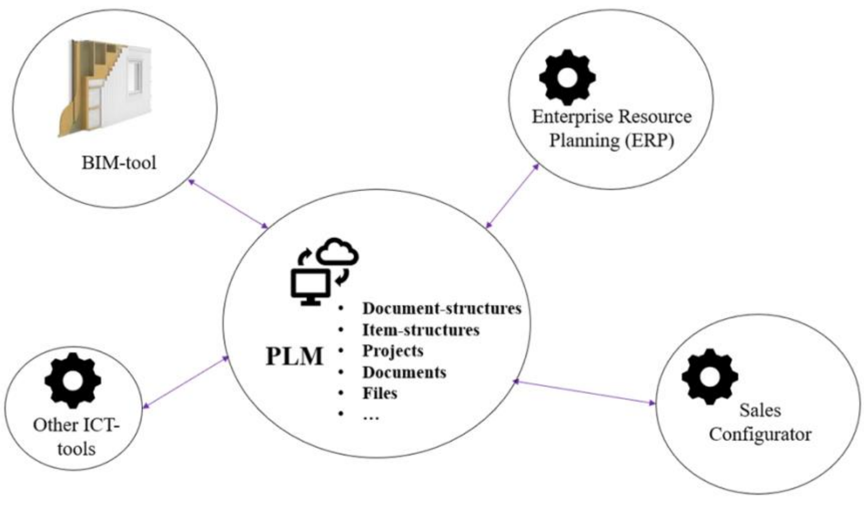

Figure 2: PLM-system, integration of ICT tools.

The general idea behind PLM is to serve up-to-date data, information, and knowledge in a secure way to all people who are part of the product lifecycle (CIMdata). Information is produced by a variety of stakeholders and different

ICT tools at different levels of detail in diverse functions inside and outside a firm. While a PLM-system is primarily about managing the digital representation of that information. Thus, a PLM-system is a system of systems, and security is achieved by, for example, restricting access via user type or group (Jun et al., 2007), Figure 2.

A PLM-system has the capability to handle product structures and integrate information to other ICT tools and thereby facilitating systems integration. With one single repository of data - all stakeholders use the same unified data (Stark, 2020).

To address challenges with product data management in IHB caused by ineffective design phase efficiency, a PLM-system solution was proposed. One of the challenges was that the sales department sold products that were outside of the product platform (Lennartsson et al., 2023). Functions developed in the PLM-system solution were process definition and generic product item. The purpose of process definition was to enable efficient project management and allow monitoring the project progression, whereas the generic product item aimed at resembling an engineering bill of materials (E-BOM). This implies that the structure does not take the production process into consideration, rather the house is broken down in logical blocks with the module on top (Lennartsson et al., 2023). Expected challenges for the PLM-system solution were the integration of a PLM-system with CAD software and an ERP-system (Lennartsson et al., 2023). The proposed PLM-system solution showed promising result to support the company in the application and enabling higher efficiency. By standardizing house types in the PLM -system and connecting them to their realizing assets (skills and knowledge) the sales department will be supported to stay within the limits of the platform (Lennartsson et al., 2023).

The advantages of PLM in construction are expected to be increased productivity, cost efficiency and sustainable manufacturing and production, optimized design, minimized production waste, managed supply chain, standardized components of products and managed product changes and adoptions (Mangialardi et al., 2017).

3. METHODOLOGY

The research presented in this paper was guided by Design Research Methodology (DRM) (Blessing & Chakrabarti, 2009). The DRM methodology is a structured approach to understand and address design-related problems (Blessing & Chakrabarti, 2009). DRM involves a variety of research techniques to gather information about user needs and preferences, as well as to identify potential solutions. The purpose of DRM is to develop an understanding of a problem and subsequently develop a support system to mitigate the problem (Blessing & Chakrabarti, 2009). The research process prescribed by DRM consists of the four stages: Research Clarification, Descriptive Study I, Prescriptive Study and Descriptive Study II. The industrial challenges that the research rests upon have been established through the Research clarification stage (Vestin & Säfsten, 2021; Vestin et al., 2021) and Descriptive Study I (Vestin et al., 2022). In this paper, results from the subsequent Prescriptive Study are presented, see Figure 3.

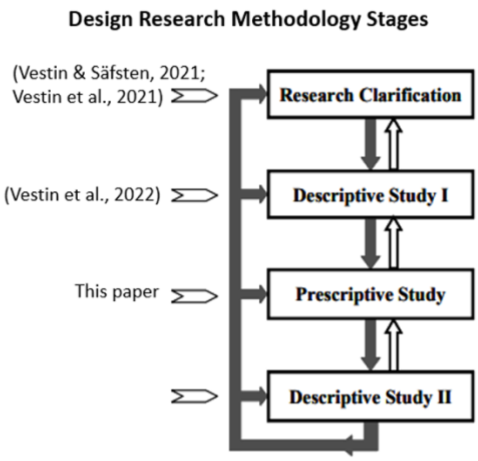

Figure 3: Design research methodology stages.

During this stage, a proposed support system was developed based on the previous stages. The focus was on identifying requirements and functions of a support system to mitigate challenges with product data management in the wooden single-family house industry. As part of the Prescriptive Study, a support system was developed, called a pilot PLM-system. The Prescriptive Study was carried out between December 2021 to June 2022 in collaboration with Company T, a Swedish wooden single-family house company, and a PLM-system solution provider. Focus during the study was on the product realization process and the addressed challenges related to product data management during this process. In the context of this paper, the design phase comes after sales in the product realization process.

The main technique for data collection was workshops. The participants during the workshops were a system developer, and the architect and construction manager from Company T and a system developer from a PLM-system solution provider. The purpose of the workshops was to identify challenges related to product data management in the product realization process and from these challenges establish requirements of a support system to mitigate said challenges, and finally to investigate what functions can be developed in a PLM-system to realize the requirements. Majority of the workshops were held online and lasted for 1-2 hours. The main author of this paper acted as facilitator and was responsible for documentation.

The workshops and related development of the support system followed the four steps: task clarification, conceptualization, realization and evaluation (Blessing & Chakrabarti, 2009). Initially, the workshops focused on task clarification to establish the challenges of product data management that were to be mitigated by the support system. During this phase, the requirements of the support system were clarified through analysis of the current situation and the desired situation. After that, the workshops focused on conceptualization to identify and decide which functions the support system needed to have to fulfill the requirements. Thereafter, the realization phase followed, when the support system was developed to enable the evaluation of the core functionalities with the available resources such as different unique BIM models. After the realization phase followed evaluation of the developed support system. The Pilot PLM-system was installed, tested, and evaluated by Company T. The support system was verified to ensure that the requirements were fulfilled. Despite the linear description here, the Prescriptive Study was iterative.

The workshops were video recorded and transcribed. The transcribed data was analyzed following the procedure for a qualitative data analysis (Miles et al., 2020). Initially, the transcribed data were coded into themes of challenges, requirements, and functions. From the identified themes, patterns were noticeable and the requirements of a support system to mitigate challenges with product data management could be established. The functions that were developed in the pilot PLM-system were established from the analysis and from within the system development process itself as progressively more was understood about the challenges and the possible functional solutions. To codify these functions in a standalone application available to any user, as independent as possible, both a desktop application and a service were developed. The desktop application utilized many application programming interfaces (APIs) to read and write information from different formats understood by different tools. A service was specifically needed to read and write information in the BIM-models utilizing the BIM-tool's API. Information and files were then stored and shared in a database and folder on a separate server. The pilot PLM-system was installed and tested several times in a real-world scenario at Company T. Different BIM models were used to evaluate the usability of the support system. The workshops helped to assess what product data is important and how it should be handled. The pilot PLM-system was developed for the BIM-tool Revit®. It was developed for a windows-based platform, utilizing the .net framework and the BIM-tool Revit.

4. FINDINGS

Company T was located in Sweden and had 260 employees. The company produced wooden single-family houses with a building system featuring prefabricated wall elements and utilized industrialized house building. The company offered two brands, one standardized, and one customizable. Both brands were usually sold under turnkey contracts and the customer was usually the end-user. The annual volume was around 300 houses and Sweden was the main market. A BIM-project was initiated when a customer had placed an order, and a BIM-model was created for each customer specific house.

4.1 Product realization process and ICT tools

The Prescriptive Study focused on the standardized brand. Although, both brands were included since it was necessary that what was developed could also handle the customizable brand. The standardized products were offered with fixed geometry, except for the options of mirrored layouts of certain rooms. The interior and exterior assortment was limited to predetermined options for the customer to choose from. Company T had a high level of prefabrication with several predefined elements and components parts. The strategy for the development of new standardized houses was to minimize engineering before a customer order. However, Company T focused on the architectural design, to be able to represent the standardized brand houses in a good way on the webpage and in the configurator. The design phase of a standardized house started first when a house was sold but if the same type of standardized house was sold again, previous engineering solutions were used to save cost and time.

ICT tools used in the product realization process were online customer configurator, employee portal, ERP-system, process monitoring, cost estimation, 2D CAD for drawings of the building system details, modified BIM-tool, two different production planning systems, business analytics, word-processors, and spreadsheets. The company used Revit ® as BIM-tool.

Over time, the company had developed their use of their BIM-tool to better suit their needs and the IHB market to become more efficient with for example, plug-ins such as wall+ ®. Company T had worked with predefined elements and components and their product platform in the BIM-tool. They had also developed BIM-families, as a collection of common components and elements, implemented across a range of products particularly for the standardized house options. The company was in the process of launching a new ERP-system with a complete item register. However, Company T had several challenges in managing product data throughout the product realization process, especially in the design phase, despite efforts to find solutions. There was a need for another ICT tool that could support them with additional functions. To mitigate their product data management challenges a number of requirements were identified, described in detail below.

4.2 Requirements of a support system to mitigate challenges with product data management

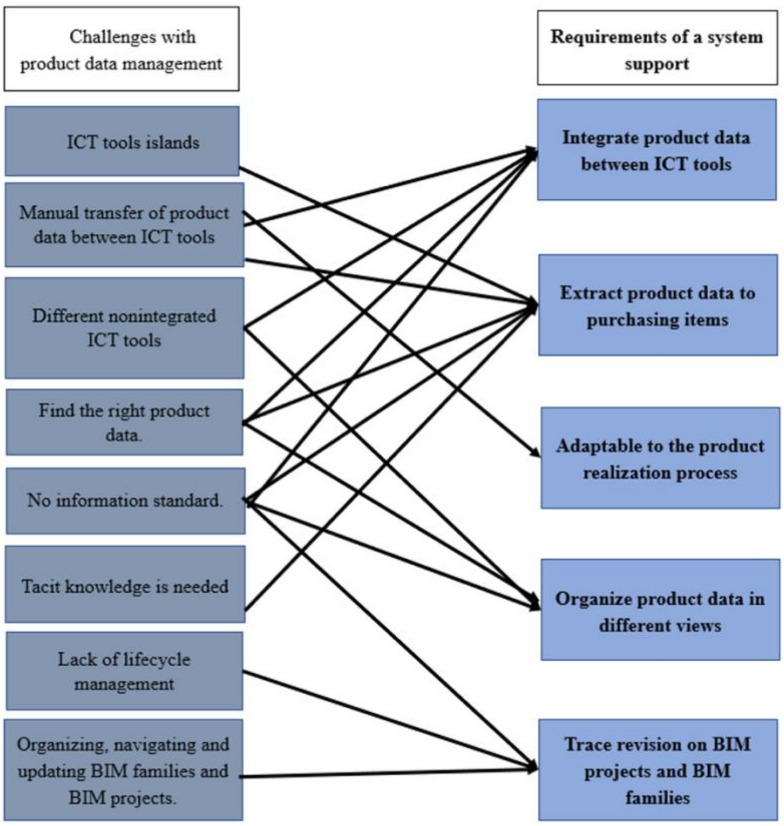

Figure 4: Challenges with product data management and associated requirements of a support system.

This section was inspired by the task clarification step of the Prescriptive Study in Design Research Methodology (Blessing & Chakrabarti, 2009). This section focuses on the challenges Company T faced in their product realization process and the requirements for a support system to mitigate these challenges. Requirements of a support system informs what a support system should do and can be defined as "the agreed-upon facts about what an application or system must accomplish for its users" (Halbleib, 2004). A requirement answers the question of what the system should do but it should never state how the system should fulfill the requirement. See Figure 4.

Figure 4 (left) illustrates the challenges encountered by company Theta in product data management throughout the product realization process. These challenges served as the foundation for identifying the necessary support system requirements (right) to mitigate these challenges.

4.2.1 Requirement 1. Integrate product data between ICT tools

The company used different ICT tools in the product realization process. A challenge was that the product data resided in different ICT tools that were not integrated, and manual transfers were needed to keep the flow of product data between the ICT tools. The company had challenges to find the right product data in the different ICT tools due to all the different starting positions and formats in which the data was stored.

A requirement was that the support system must act as a bridge between these different ICT tools and make it possible for certain product data to flow in between ICT tools. For example, product data from the BIM-tool can be extracted to the support system and the data from support system can be delivered to the ERP-system. Furthermore, a requirement was that the support system should be the single source to secure trustworthy and up-to-date product data. It was required that product data could move both ways, as one example, from BIM-tool to the support system and from the systems support to the BIM-tool. This was to minimize the number of times product data was entered into a system.

4.2.2 Requirement 2. Extract product data to purchasing items

One of the main challenges with product data management for Company T was purchasing of joists, wainscot, insulation, electrical boxes, etc. For purchasing, all the relevant product data needed to be gathered from all different sources/ICT tools and inserted into the ERP-system. A challenge for the company was that tacit knowledge was needed to navigate the ICT tools to perform purchasing.

Among other ICT tools, a BIM-tool was used to model a large part of that product data and there was a lack of integration between the BIM-tool and ERP-system and other ICT tools which caused manual transfer of product data. As a requirement, the systems support should make it easy to find relevant items for purchasing in the BIM model and from other ICT tools. With few operations, the relevant items need to be transferred into the ERP-system. Preferably, this should be done, using programmable intelligence with some kind of "filter" to extract the relevant items and quantities for purchasing. The support system needs to be reliable and give a signal when relevant items have not been transferred to the ERP-system.

4.2.3 Requirement 3. Adaptable to the product realization process

The company strategy for the product realization process was to start the design process after customer contact, even for standardized houses. During the early stages of the product realization process, the BIM-model contains less product data, so called incomplete models. Nevertheless, this data could still be used as a support to indicate price to the customer. At the time of the study, the company made use of this product data in a separate ICT tool through manual transfer of the data.

A requirement on the support system was that it must be able to adapt to the product realization process. The system must be able to use the product data in the BIM model at any point during the product realization process and with few operations support to indicate price to the customer, even if the model is incomplete.

4.2.4 Requirement 4. Organize product data in different views

The company had challenges to find the right product data in the different ICT tools due to all the different starting positions and formats in which the product data was stored. Provided that the support system could be the single source to secure trustworthy and up-to-date product data, as mentioned in requirement *Integrate product data between ICT tools*. The company's additional requirement was that the support system should provide a way to sort the product data from the BIM model in relevant pedagogical structures for employees to easier find product data. How to structure the product data depends on where in the process you are and what product data is relevant for whom, and especially what product data is relevant for purchasing.

4.2.5 Requirement 5. Trace revisions on BIM-projects and BIM-families

Company T had developed their product platform in the BIM-tool with advancement of BIM-families. The BIM-families should be used as a collection of common elements, implemented across a range of products, particularly for the standardized house options. However, the company had challenges with making and tracking changes to the BIM-families due to lack of revision control. It was not known which projects had which versions of BIM-families. This made it difficult to assess how big the consequences of a change to the families were, especially if something was wrong with an existing family or a performance upgrade. Furthermore, the traceability of which BIM-family was used in which BIM-project caused ambiguity about how much product data was shared between projects, which in turn could be an important source for efficiency through synergy and for finding previously used solutions. The company had a similar challenge when it came to BIM-projects. Oftentimes, each customer project works with its own non-linked BIM model copy and the company had challenges to find the right version of the customer BIM-project.

The company requirement of a support system was that the system should facilitate revision management, i.e., Company T wanted control over their BIM-families and BIM-projects. They wanted to have traceability of revisions made, by whom, and which revision was the latest and ensure that employees were using the latest updated version of the BIM-family or BIM-project.

4.3 Functions of a support system to mitigate challenges with product data management

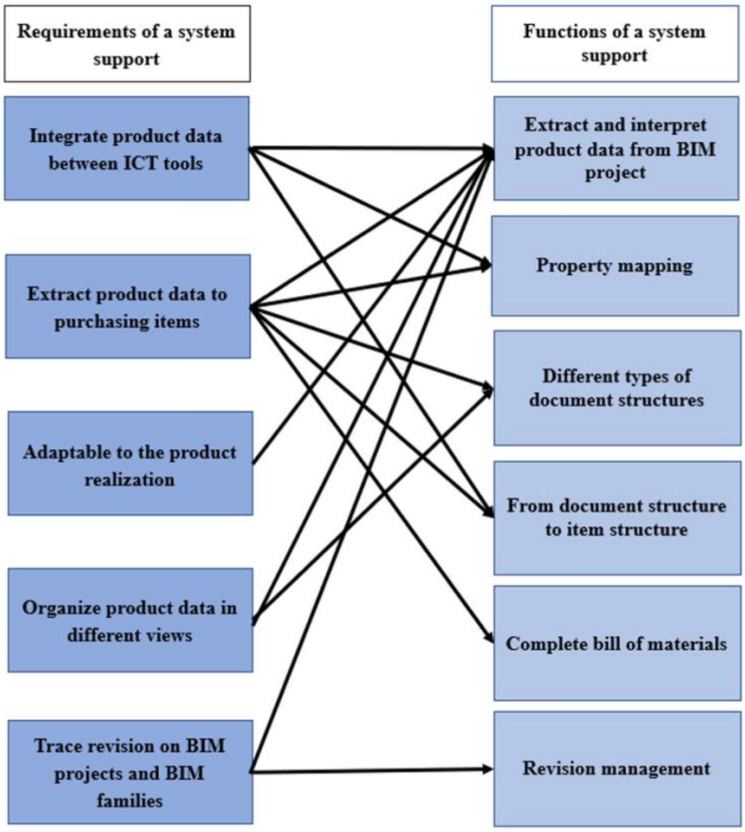

Figure 5: Requirements of a support system and resulting functions developed in the pilot PLM-system.

This section was inspired by the conceptualization, realization and evaluation steps of the Prescriptive Study in Design Research Methodology (Blessing & Chakrabarti, 2009). The developed system functions presented in this chapter are based on the company requirements of a support system to mitigate challenges with product data management. A function instructs the support system to perform certain operations to fulfill a requirement. See acknowledgement for a link to a demonstration video of the pilot PLM-system, see Figure 5.

Figure 5 (left) illustrates the requirements of a support system to mitigate the identified challenges. These requirements served as the foundation for developing the functions in the pilot PLM system (right) to mitigate the challenges with product data management.

4.3.1 Function A: Extract and interpret product data from BIM-project

This function was about extracting product data from the BIM model, interpreting the product data and representing it in the support system. The BIM-tool was used to model a large part of the product data and therefore product data that was needed for different situations had to be extracted and interpreted. Situations when this was relevant was for example for creation of an item structure, to support purchasing and to structure product data in a relevant pedagogical view for employees to easier find product data (see function *different types of document structures*). Data regarding the BIM instances were related to their context. For example, which BIM-family, BIM-family type, system families, part of a room, level, host, etc., they were a part of.

This function was important at different stages in the product realization process and on incomplete BIM models. For example, the product data in the BIM model could be used in an early stage of the process as a basis to indicate price for a customer.

4.3.2 Function B: Property mapping

It was required that product data can move two-ways, from BIM-tool to support system and from support system to BIM-tool, to minimize the number of times product data had to be entered into an ICT tool. This function made sure of that. Not all product data was modeled in the BIM-tool, for example, color on windows and doors were not modeled, see the requirement *Integrate product data between ICT tools.* However, some product data that was not modeled in the BIM-tool but was still of value to have in the BIM model. If that type of product data was added in the support system, it should also have updated the BIM model with that product data. Another example was project information like customer, seller, house model etc. If that information was entered into the support system, the BIM model was also updated with that information.

This function could be used to extract properties of the product from the BIM model mainly that were of interest for purchasing. For example, area, length and volume of a wall element to indicate, for example, how much insulation was needed to be purchased for that particular wall element.

4.3.3 Function C: Revision management

The function was to provide revision management for BIM-families and BIM-projects. This was to get traceability of made revisions, by whom they were made and which revision was the latest. This function was expected to ensure that employees were using the latest updated version. This function was also needed to make it possible to trace a specific BIM-family and see in which BIM-projects it was used and what revision was used.

4.3.4 Function D: Different types of document structures

This function was to provide a way of sorting the product data from the BIM-model in relevant pedagogical structures for employees to easier find product data. The way to structure the product data depended on where in the process you were, what product data was relevant for whom and especially what product data was relevant for purchasing.

In the developed function, product data was sorted on Level-Room-Instance, Host-Instance, Assembly-Type, and Assembly-Littera. For purchasing, the document structures of Assebly-Type and Assembly-Littera were most relevant. They were a foundation for the item structure of a wall element since many family types represented a specific purchasing item and the instances were used for quantity and location.

4.3.5 Function E: From document structure to item structure

This function was about interpreting a document structure from the BIM-model to an item structure that could for example be used for purchasing. With this function, the user could change a document structure of the assembly wall element (Assebly-Littera) to an item structure. The document structure from the BIM-model contained only what was modeled in the BIM-tool, i.e., not a complete structure. It was desirable to have a complete structure of all physical parts that the product consisted of. For example, what needed to be kept in stock, manufactured or ordered, but also non-physical parts such as instructions, software etc. Instead of modeling / adding these in the BIM-tool, this function could create a separate structure in the support system, a so-called item structure, the item structure made it possible to group together product data from different ICT tools to create a complete item.

However, it required some manual operations the first time to map family type to purchase items in order to get the item structure. When the document structure was changed into an item structure, there was also an intelligence in the support system that executed the linking of the purchase items, for example, joists. The function provided an item structure with purchase items and a basis for a BOM for the product data contained in the BIM model for an assembly wall element.

4.3.6 Function F: Complete bill of materials (BOM)

The document structure from the BIM-model was not complete, it only contained what is modelled in the BIM-tool. Complete houses with all its items are not modeled as it would take too much time and be counterproductive. Nevertheless, as mentioned above, an item structure must include all physical parts that make up the product. The function Complete bill of materials (BOM) was about adding relevant items from other ICT tools that were needed to make a complete item structure to generate a complete bill of materials that could be used as a basis for purchasing.

It was important that this product data could be easily found/transferred and that the function could be performed with as few operations as possible. For example, insulation component in a wall element was not modelled in the BIM-tool, thus it was not a part of the document structure but should be a part of the item structure as insulation was needed to complete a wall element. In the support system for the complete BOM function, the focus was on a panelized wall element. For the complete item structure, a report could be generated in the form of Excel. The complete list of purchase items could then be managed in the ERP-system for the execution of purchases, inventory etc.

4.4 Summary of findings

Table 1: Challenges of product data management associated requirements of a support system and resulting functions developed in the pilot PLM-system.

Challenges with product data management	**Requirements of a support system**	**Functions of a support system**
Different nonintegrated ICT tools. Manual transfer of product data between ICT tools. Find the right product data.	**1. Integrate product data between ICT tools**	A. Extract and interpret product data from BIM-project B. Property mapping. E. From document structure to item structure.
ICT tools islands. Manual transfer of product data between ICT tools. Find the right product data. Tacit knowledge is needed.	**2. Extract product data to purchasing items**	A. Extract an interpret product data from BIM-project B. Property mapping. D. Different type of document structures. E. From document structure to item structure. F. Complete bill of materials.
Manual transfer of product data between ICT tools.	**3. Adaptable to the product realization process**	A. Extract and interpret product data from BIM-project.
Find the right product data. Different nonintegrated ICT tools.	**4. Organize product data in different views**	A. Extract and interpret product data from BIM-project. D. Different type of document structures.
Organizing, navigating, and updating BIM families and BIM projects.	**5. Trace revision on BIM-projects and BIM-families**	A. Extract and interpret product data from BIM-project. C. Revision management.

During the study, the challenges with product data management have been translated into requirements of a support system. Based on these requirements, system functions have been developed in the pilot PLM-system. In table 1, and overview of challenges, requirements and developed functions are presented. The requirements were empirically derived from Company T and the process of developing requirements and functions is described in detail in chapter 3.

4.4.1 Development of the pilot PLM-system

The workshops and related development of the support system helped the participants comprehend the challenges and requirements on a deeper level, but also the potential and design of a PLM-system as the support system. When the study started it was unknown if a PLM-system was feasible. An existing PLM solution was gradually adapted to the context of the wooden single-family house industry by the solution provider. This was done mainly to explore PLM-system as a solution to the challenges, but also indirectly to reach an improved understanding of the main product data management challenges, as many questions arose in the workshops and development work. Company T shared their challenges related to product data management and put forward requirements needed in a support system to mitigate the perceived challenges. Company T also participated in the development of the pilot PLM-system by, for example, sharing their product realization process, suggesting solution alternatives, posing questions, testing and providing access to real BIM-models to work with.

5. DISCUSSION AND CONCLUSION

The purpose of this paper was to elaborate on requirements and functions of a support system to mitigate challenges with product data management in the wooden single-family house industry. A pilot PLM-system was developed to mitigate the perceived challenges. The development of the pilot PLM-system followed the steps of a Prescriptive Study including task clarification, conceptualization, realization and evaluation (Blessing & Chakrabarti, 2009). In total, five requirements for a support system to mitigate challenges with product data management were established; *Integrate product data between ICT tools*, *extract product data to purchasing items*, *adaptable to the product realization process*, *organize product data in different views* and *trace revisions on BIM-projects and BIM-families*. A pilot PLM system was developed with six functions to fulfill the requirements, the functions were, *extract and interpret product data from BIM-project*, *property mapping*, *revision management*, *different type of document structures*, *from document structure to item structure* and *complete bill of materials*.

The pilot PLM-system was developed for Company T representing industrialized house building. Company T was a wooden single-family house builder that employed a combination of a project-oriented strategy with a process- and product-based strategy in the product realization process. Company T had a high vertical integration of the value chain and used predefined elements and components in the design phase. Company T could manage activities ranging from design and manufacturing to assembly and delivery, giving them greater influence and control over the entire product realization process.

The developed pilot PLM system fulfills the empirical derived requirements for a product data management support system and addresses some of the product data management challenges previously reported in the literature. The main focus of the pilot PLM-system was to facilitate systems integration between the pilot PLM-system, BIM-tool and ERP-system in such a way that it would increase value for the customers through improved product quality and performance while at the same time provide value to the company by for example, reduced operational costs and improved response time (Mische, 2002; Vonderembse et al., 1997). The pilot PLM-system can handle product structures with the developed functions of, *different type of document structures*, from *document structure to item structure* and *complete BOM,* which is a prerequisite for a successful information transfer between ICT tools (Boton et al., 2016; Jupp, 2016; Mukkavaara et al., 2018) and systems integration (Lee et al., 2011). PLM-systems typically have this functionality as opposed to BIM tools, which are unable to manage product structures (Biccari et al., 2018; Boton et al., 2016).

The findings in this paper add knowledge to existing research on mitigating challenges with product data management in IHB (Lennartsson et al., 2023; Mukkavaara et al., 2018), as well as existing research on system integration in IHB (Turk, 2020). A demonstration tool developed by Mukkavara et al. (2018) mitigated challenges of managing information and enabling diverse views on information. In that study, the solution used BIM data to generate an engineering view on the BOM, referred to as an E-BOM (Mukkavaara et al., 2018). The solution generated a BOM that provided a view of a building based on its composition, and how individual modules and walls were composed. However, it was unclear if all necessary product data was in the BIM data. The pilot PLM-system presented in this paper expands beyond using data only from a BIM model. The reason for this was that a BIM-model usually only contains what was modeled in the BIM-tool, typically not a complete structure. It is desirable to have a complete structure of all physical parts that make up the product. Instead of modeling/adding these in the BIM-tool, the pilot PLM-system can create a separate structure, a so-called item structure, that makes it possible to group together product data from different systems, for example the ERP-system, to create a complete item. The solution developed by Mukkavaara et al., (2018) can be related to the requirements identified in this case study, *organizing product data in different views* and the thereby related functions *different type of document structures* and *from document structure to item structure*. The solution in the demonstration tool developed by Mukkavaara et al., (2018) does not target how to transfer information between systems, but rather how to describe a house product in a way that facilitates this information transfer. The pilot PLM-system developed in this paper cannot only generate a BOM, but a complete BOM and targets how to transfer information between systems. BOM is the core of information systems and an essential part in the ICT toolkit (Hegge & Wortmann, 1991). The BOM from the pilot PLM-system can easily be adjusted depending on which ERP-system and what file format is used.

A PLM-system solution was proposed by Lennartsson et al., (2023) to mitigate challenges of lacking efficiency in the design phase, especially with sales department selling products that are outside of the product platform. Functions developed in the PLM-system solution (Lennartsson et al., 2023) were process definition and generic product item, to resemble an E-BOM (Lennartsson et al., 2023). The generic product item function corresponds to the requirement *organize product data in different views* and the functions of *from document structure to item structure*. The pilot PLM-system developed in this paper is expanding on the generic product item to a specific product item. If Company T saves a specific customer BIM project into the PLM-system, the PLM-system can generate a specific item structure for that house. The function of process definition was not developed in the pilot PLM-system presented in this paper, although it was discussed during the workshops. Company T had an ICT tool with this function. Nonetheless, process progression is a function that would be developed if the pilot PLM-system would be implemented. For the PLM-system solution, expected challenges were within the integration of a PLM-system with CAD software and an ERP-system (Lennartsson et al., 2023).

Previous research has put forward PLM-systems as a possible solution to mitigate challenges of product data management in IHB (Aram & Eastman, 2013; Holzer, 2014; Mangialardi et al., 2017; Turk, 2020). However real-world testing of PLM-systems in IHB is scarce (Mangialardi et al., 2017). The study presented in this paper is an example of the development and real-world testing of a PLM-system to facilitate integration between PLM-system, BIM-tool and ERP-system in IHB. The pilot PLM-system was installed and tested in a real-world setting by Company T with different unique customer BIM-models. The functions developed were perceived to have value and could, for Company T, mitigate their challenges with product data management and facilitate systems integration between the pilot PLM-system, BIM-tool and ERP-system. Hence, apart from clarifying what the requirements and functions of a support system were, the paper adds new knowledge regarding which ICT tool can be a suitable support system. A PLM-system seems to be feasible, and it might be a way to mitigate challenges with product data management in the wooden single-family house industry. Moreover, the paper contributes to the existing knowledge on product data management in the wooden single-family house industry through the pilot PLM-system and the description of how it can be developed.

Based on the findings of this study it is evident that PLM-systems should not replace BIM-tools (Jupp, 2016). BIM-tools and PLM-systems should work together. This is also consistent with the literature, which proposes that BIM tools play an indispensable role and future digital technology development should be built on the existing BIM tool to expand its capabilities (Cheng et al., 2023). Moreover, previous efforts to address product data management challenges in IHB, as referenced by Lennartsson et al. (2023) and Mukkavaara et al. (2018), were based on product data from the BIM-tools. From discussions during the workshop, it was clear that there are opportunities to optimize how product data is modeled and labeled in the BIM-tool to facilitate the extraction and interpretation of product data from BIM-projects to the pilot PLM-system.

The result in this paper can support managers in the housebuilding industry to improve product data management in the product realization process. The empirically derived requirements can be used as foundation for discussion with solution providers of support systems to mitigate challenges with product data management.

It should be mentioned that in addition to the developed support system in this work, there may be other ways to design a support system that can satisfy its requirements. For example, it may be possible to directly integrate the BIM-tool and ERP-system (Babič et al., 2010).

However, this type of solution can make it complicated to support revision management, calling for further studies. The support system developed and presented in this paper was a pilot PLM-system and more case studies on the topic are needed. Companies need to evaluate the requirements and functions developed in the pilot PLM-system, preferably with a different building system in use. Future studies are also needed to consider the possible implementation, development and implications of such a support system in IHB.

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Demonstration of the pilot PLM-system: https://www.youtube.com/watch?v=9fOERlR_8VY&t=2421s

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