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MANAGING PRODUCT INFORMATION FOR LEAN CONSTRUCTION: USE CASES AND A PROPOSED PROCESS

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ABSTRACT

This paper explores how the flow and management of product information could enable lean construction operations. Recent research has underlined the need and possibilities to integrate product information with building information modelling (BIM). This research extends that knowledge by investigating more thoroughly (1) what are the use cases in construction project life cycle for product information management (PIM)?, and (2) what kind of solutions and processes would support these use cases in lean and BIM-based building projects? Design science approach was used to identify six common use cases for PIM and to identify sub-solutions. In total 36 representatives from Finnish Architectural, Engineering and Construction (AEC) companies are used as informants and participants in workshops. Finally, a process for the PIM was proposed based on the use cases and the identified sub-solutions. The process helps construction practitioners in their efforts towards smoother product information flow which finally contributes on better operations flow in building projects.

KEYWORDS

Lean construction, Supply Chain management (SCM), Logistics, Product information management, BIM

INTRODUCTION

Product information is important for improving flow and maximising value, and thus better access to timely and accurate product information is aligned with the goals of lean construction (Koskela, 2000). In particular, owners, users and administrators are interested in the traceability of the building's products and materials: what products are installed in the building and how they should be maintained and used (Cavka et al., 2017; Watson et al., 2019; Wang et al., 2020)? This information adds value to them because climate targets require that the carbon footprint of buildings can be calculated accurately based on environmental data of the manufactured products (e.g., European Commission, 2021). The safety and health of buildings is also becoming increasingly important to owners. More will be required of the materials and their properties, and manufacturers have to demonstrate the safety of the products. In addition to increased value, improved product information can play an important role in ensuring that requirements are passed

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down from the designers to the installer, optimizing logistics, and ensuring quality by having access to up-to-date instructions specific to a certain product.

Recent research has underlined the need to integrate product information with BIM (Berard and Karlshoej, 2012). The focus is shifting from BIM technology to BIM-based processes. Nummelin et al. (2011) developed a BIM-based PIM procedure for the supply chains in industrialized construction. They envision how BIM-based supply chain management between a contractor and product suppliers should enable identification of construction products and building parts digitally in various systems, utilization of BIM in cost estimation and tendering process, access to accurate product and quantity information to site staff, improving logistics of incoming materials on site, and recording as-built-data into BIM or database. Later, Palos et al. (2014) presented a BIM compatible product library process, which indicates how native models could function as a platform from which the required information is extracted by different applications in procurement, construction, and maintenance. Latest research by Lucky et al. (2019) focused on defining a common data structure for product information and using existing technologies to share this data. Data templates are suggested to foster mutual understanding and efficiency in information management at product type level (Meda et al., 2020).

The previous studies on PIM mostly focus on defining data content, BIM process or key areas for product data use. This research extends this knowledge by investigating (1) what are the use cases in construction project life cycle for product information?, and (2) what kind of sub-solutions and processes would support these use cases in building projects which utilize BIM, and aim at smooth flow of product information? Lean is used as a lense in the analysis by aiming at smooth flow (Phelps, 2012) of enriching and linked product information throughout the project lifecycle. Previous research suggests that poor design information flow causes significant waste for the following activities in the construction process (Al Hattab and Hamzeh, 2017). Similarly, this research hypothesizes that poor product information flow leads to remarkable manual work and waste in construction operations, and practitioners would benefit from knowledge on thorough processes on lean management of such product information in their building projects.

This paper explores how the flow of product information could be improved during a construction project. Product refers to a permanent building component, structure, or an accessory, or device integral to the construction site. The building consists of different products, which are mostly Make-To-Stock (MTS) standard products or Engineered-To-Order (ETO) products which could be variants modified from commercial products or unique building components designed separately for the project.

Information related to products can be divided into a) standard information, b) instance information, and c) process information (see, e.g., Lucky et al., 2019). Standard information includes e.g., product dimensions (e.g., length, weight), performance characteristics, and material and packaging information. The usability of standard information depends on how it is enriched with instance and process information. Instance information refers to the unique identifier of a particular product individual and the specific information of that individual. Process information, in turn, refers to e.g., timestamps, location codes, and employee information, related to the processing, distribution, location, and use of a product individual.

RESEARCH METHOD

The design science approach was chosen because it enables designing an artifact as a solution (process) to the identified problem (use cases) that practitioners face in a proper context (Pfeffers et al., 2007). In practice, the management of product information was investigated with the help of two sub-objectives. The first objective was to identify use cases for product information flow, enrichment and utilization in the design and construction process. The second objective was to develop a process with embedded solutions for the effective management of product information, including standard, process and instance information, to meet the above needs. Here, the solution refers to partial components of the overall PIM process, including existing commercial solutions as well as new type of solutions enabled by existing technologies.

The research methods included expert interviews, documentary analysis of existing solutions, and four focus group discussions (FGDs) conducted in Finland (Figure 1). As an output of the first FGD, six construction products representing various construction product classes (Finnish Talo 2000 system) were selected for further investigation: recessed ceiling light (P1), window (P2), ready-mixed concrete (P3), partition wall (P4), interior paint (P5), and wood product (P6). The selected products are different in size, technology, material and design process. The window and partition wall are designed for the project while others are standard MTS or MTO (Make-to-Order) products.

For each product, expert interviews were conducted to explore: 1) what are product information use cases in this product? 2) what information is needed? 3) who needs the information and for which purpose? 4) what are the current challenges in PIM with that product? and 5) what opportunities exist for proper PIM with that product? In total 36 professionals, representing designers, general and trade contractors, logistics operators, project management services, IT companies and hardware stores, were interviewed. Based on the interviews, six common use cases were identified and then elaborated and validated in the second FGD. Next, separated interviews and document analysis (mostly web documents) were utilized to determine which existing partial solutions, including commercial solutions and technologies, would support PIM in each use case. The relevance of the solutions was validated in the third FGD. Finally, a proposed process of the PIM was formulated as a synthesis of the use cases and the identified solutions. The process was validated in the fourth FGD. Participants in the four FGDs overlapped. The expert interviews included mostly informants who were not present in the FGDs.

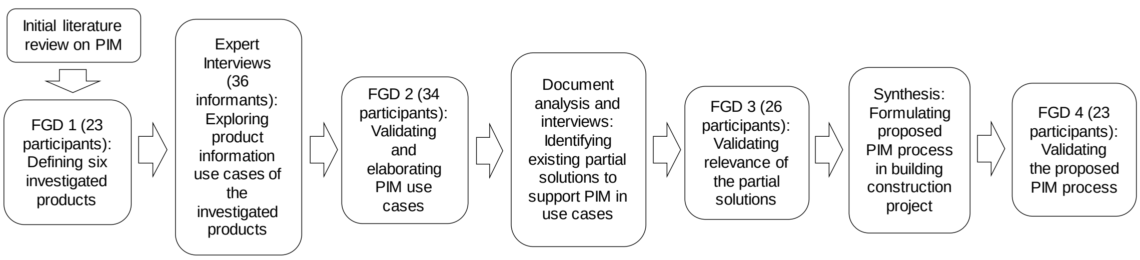

Figure 1 The research process

RESULTS

USE CASES FOR PRODUCT INFORMATION

Table 1 provides a summary of the challenges and opportunities of managing product information for the six products under review. In some products, different actors should have access to product information because the product is affecting several tasks around the product. For example, recessed ceiling lamp affects the work of ceiling designer and installer. On the other hand, windows have many different requirements, but their information can be handled separately from other products and actors as interface between the window and building is rather clear.

Table 1 Product-specific notes on product information

Product	Challenges	Opportunities
P1. Recessed ceiling lamp	Related to many other products and factors, e.g., suspended ceiling designer and installer	Basic and easy access to basic product information
P2. Window	Several different requirements and features	The interface of the product to the rest of the building is quite clear
P3. Ready-mixed concrete	The final location of the deliveries in the structure is usually unclear	A lot of information is already being collected on manufacturing, transportation, and casting
P4. Partition wall	Consists of several sub-products; associated with Mechanical, Electrical and Plumbing (MEP) systems and furniture; deliveries often in bulk	Management of product data of by-products by means of a cost structure; room-specific material deliveries (kits)
P5. Interior paint	The product consists of a standard product and additives; storage and condition information critical	National painting classifications indicating possible combinations of standard products and additives
P6. Wood product	The origin often difficult to determine; products from different suppliers mixed in the supply chain	Product similarity, the number of suppliers quite limited

Ready-mix concrete differs significantly from the recessed ceiling lamp and window, as it is purchased in loads and typically from a standard supplier. If quality problems occur, the exact disposal location of concrete is practically impossible to determine which makes it impossible to connect defects with a particular load after casting.

The partition wall is an ETO product, consisting of standardized MTS products, such as frames, gypsum boards and insulation, and the product information of all of these. Interior paint, on the other hand, differs from others as it consists typically of two components, namely a primer and a tint, and the information of these both components.

Wood products cover several variants from simple lumber to the Cross-laminated timber (CLT) element. In all wooden products, there is a need to know the origin of the wooden material. This will be emphasized in the future as traceability needs and environmental certification become more widespread.

GENERAL USE CASES OF PRODUCT INFORMATION

Based on the interviews and workshops, six key recurring use cases of product information were identified. Table 2 describes these use cases and for which products they are relevant (P1-P6), the users involved, and the possible solutions for PIM.

Table 2 Generic use cases

Use case (associated products)	Users	Possible solutions
Structured design information for efficient procurement and cost estimation (P1-P6)	Procurement, cost estimating	Standardized data templates for design and commercial products → tools for product search and comparison
Efficient process to suggest and approve substitute products (P1, P5, P6)	Contractors, procurement, designer, client	Process software; use of data templates for product types, product libraries

Calculating environmental footprint for building (P1-P6)	Designers, procurement, site managers	Environmental Product Declarations (EPD), Carbon budgeting tools
Coordinating material deliveries on site (what, whose, where) (P1-P6)	Logistic, site management, sub-contractors	Identification codes (products, batches, individuals); readers/trackers (bar code readers, RFID, crane cameras); links to product libraries and project data
Access on site to space- and element-specific products and instructions (P1-P6)	Workers, site managers	Codes and tracking technologies; products linked to BIM models; user interface from building model to product information
Access to as-built product information in maintenance and use phase (P1-P6)	Maintenance, user, owner	Products (individuals) linked to as-built BIM models; user interface from maintenance model to product information (Virtual Reality etc.)

Structured design information for efficient procurement and cost estimation

Based on the data provided by the designer, the procurement of the contractor selects a suitable product for the project. The problem is often that the design information is not structured and comprehensive, and finding suitable commercial products requires a lot of manual work. A structured and product type-specific standardized presentation of design information would enable the streamlining of procurement and cost estimating processes.

Efficient process to suggest and approve substitute products

When the contract includes both products and their installation, the contractor often has an opportunity to propose a replacement product alongside the product specified by the designer. The analysis showed that the process is not transparent and efficient, and the designer's consultation and supervisor approval can take a long time. Also missing information about the product will be completed along the way. The acceptance process would be enhanced by a process tool built on structures and standardized product information. In the tool, the contractor can propose a replacement product and the approval processing proceeds automatically from one project party to another, for example in the form of task requests and links to e-mail.

Calculating environmental footprint for building

The third use case is related to the calculation of the environmental footprint based on product information. Three phases to determine a carbon footprint were identified: 1) planned, 2) procured, and 3) constructed carbon footprint. The planned footprint must be calculated based on design information; quantities of building components and materials derived from them. In that phase, the calculation should be based on product benchmarks or average data. The procured commercial product must obtain the carbon footprint provided by its manufacturer for the implementation of the carbon budgeting defined in the design. The environmental statements of the products and their data on the carbon footprint is the key information to be used. The constructed footprint verifies that the delivered and installed products lead to the carbon footprint defined in the procurement. The built carbon footprint also considers site functions, such as the use of energy and transportation, which are not directly related to any commercial product.

Coordinating material deliveries on site

After the final selection of the product, the identified key use case was related to the management of product delivery from the supplier to the construction site and to the installation within the site. In that activity, it is central to identify a physical product or batch and to associate that with a specific contractor and installation location. Access to packaging information and storage instructions may be essential for logistics. A key part of the solution in coordinating material deliveries is machine-readable product and batch identification codes. Technological solutions, e.g., using QR and RFID codes in physical product and batches, could play a key role in identifying products on the job site.

Access on site to space- and element-specific products and instructions

From the various site actors' point of views, access to the information of the products to be installed on the site, especially their installation instructions, technical dimensions, and other features, are essential. This use case can be divided into two: first, there may be a need to find out the information and features of the product to be installed in a particular space of building before the product is physically on site. This requires a user interface to a space or building object model from which there is an easy access to the selected products and their features. On the other hand, there is often a need at the site to find out more detailed information about the product on the construction site, for example regarding installation instructions.

Access to as-built product information in maintenance and use phase

The sixth use case identified in the study concerned access to as-built product information during the operation and maintenance phase. Although this research was mainly limited to the design and construction phases, it is appropriate to consider the needs for operation and maintenance, as the starting points for the usability of the information are often created already in the project phase. Access to the product information is important both through the building's data model and the machine-readable identifier of the physical installed product.

SOLUTIONS FOR PRODUCT DATA FLOW

This chapter delves into the identified and validated sub-solutions to manage and utilize product information. The use cases were connected to several existing solutions and technologies. Figure 2 shows the partial solutions in a way that solutions shown on the left create the basis for the development and implementation of the solutions on the right.

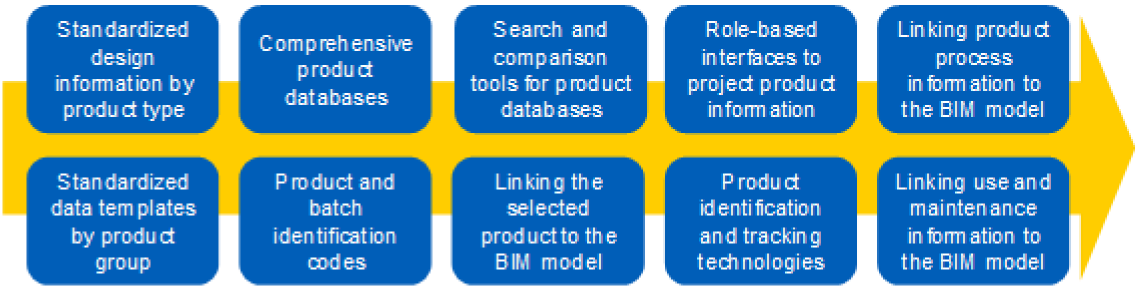

Figure 2 Partial solutions for product information management

Standardized design information and data templates by product group mean that it is defined at the product group level what information should be presented in the design information and what corresponding information should be provided by the manufacturer for its products. This means jointly agreed data templates for the information content (Meda et al., 2020). International classification standards, such as ETIM (international classification standard for technical products), should be favoured. The definition work requires cooperation between designers and manufacturers.

Standardized information is a prerequisite for the comprehensive product databases. Comprehensive information on all products on the market should be found in open databases. If the content of information is not structured, quantified and comprehensive, the benefits of the database will be reduced, especially at the procurement phase.

Comprehensive and structured databases enable the development of search and comparison tools to review products and facilitate selection. Some tools are already available, e.g., in Finland for electrical products. The tools can also be used when contractor proposes a substitute product. Transparent and usable tools also increase pressure on better and more comprehensive product information.

A key feature of product databases is the identification code assigned to each commercial product. The study suggests the use of international identification codes, such as GS1 GTINs, which allows developed systems to operate in international business and flexible addition of new products to supply chains. Use of a particular code system enables investing in applications to manage product information and logistics processes. The unique identifier of the delivery batch SSCC is also useful in construction. With help of SSCC the received materials and products can be read on site, and a stock balance can be maintained. The serialized GTIN could be used to identify which product instance was installed in certain space or element. This way, in problematic situations, it is possible to trace all the way back to the product and the production batch.

International standards also support the development of identification systems for logistics management. Technologies, whether based on RFID, QR barcodes, or image recognition, enable product flow tracking as well as machine-readable access to product information. Through codes it is possible to access all the information of the product.

To truly benefit project management, the FGD suggested that the identification codes must be linked to other information of the project, such as BIM objects, plans and scheduled tasks. Previous research (Berard and Karlshoej, 2012) suggested using product-specific objects developed and maintained by the manufacturers, instead of using generic objects. However, this study indicated that the links from generic BIM objects to product-specific information could be an efficient solution. Linking selected products to the project's 3D-5D model is essential, especially when the builder's standard products guide the design. Additional tools have been developed on top of the modelling programs, with which product information from the databases can be linked to the building and space objects. In one case, the builder developed an own database between the general product database and the design program, including the products approved in their projects.

Role-based user interfaces help access to the BIM-linked product information. Design software is intended for design and designers, and therefore product information should be accessible separately, e.g., from a browser-based tool. The FGD also highlighted the need for role-based data filtering tools. A filter could form compact product information packages for needs of different roles, both for procurement and site personnel.

For utilization of product information, it is also central that process information related to the status of the product (who did what and when?) is linked to the BIM elements. Using integration between the product tracking and the BIM objects, the BIM could be enriched by process information. Through a unique product identifier, all information related to the product supply chain can also be linked to the BIM. After the project, the information model can be further enriched with operation and maintenance data. Linking the process information of project and operation phases to the model generates the information content needed in the digital twin of the building.

PROCESS FOR PRODUCT INFORMATION FLOW

Based on the validated partial solutions, the process which combines the results and visualizes the possibilities of enriching and smooth flow of product information, was defined. Separate versions for MTS and ETO products were described, however, due to space limitations, this paper presents only the validated process for MTS products (Figure 3). The embedded BIM process in the overall process represents the enrichment of the building information from product requirements to selected products and their standard information, and finally including also process and instance information of each individual product assembled into the building.

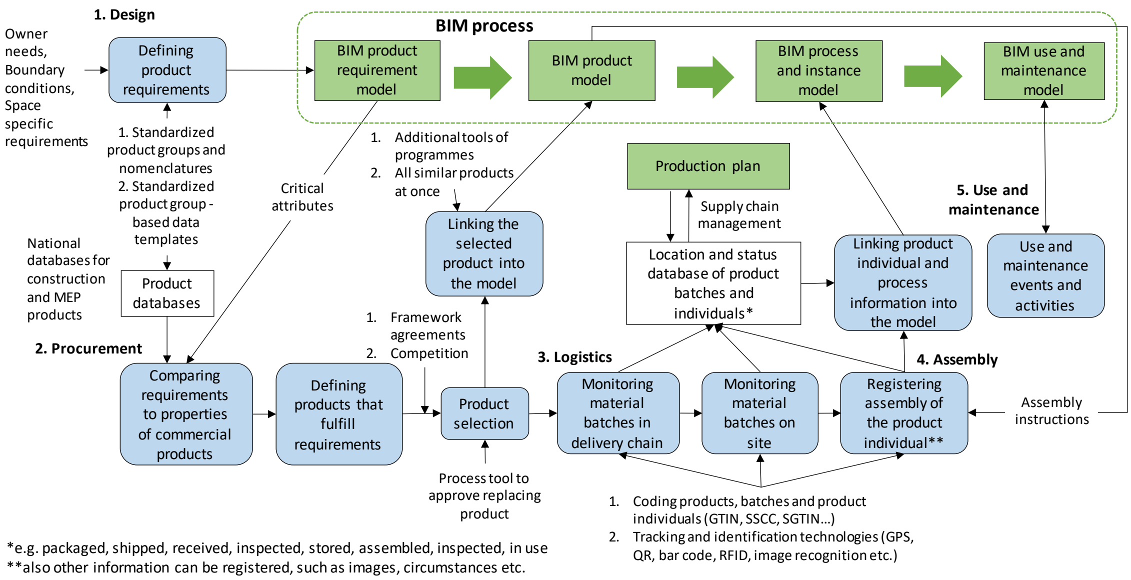

Figure 3 Proposed process for product information management of MTS products

The process begins with the design phase, in which requirements for the products are defined based on customer needs, the project's boundary conditions, and the space-specific requirements. The requirements are defined based on standardized product groupings, nomenclatures, and data templates. The requirements are presented in the same way as the corresponding information in the product databases. A BIM product requirements model presents the building with design information and product requirements related to its sub-products.

Product requirements are then used in procurement. The purchaser uses critical characteristics defined by the designer to determine which products in databases are possible to this project. The final selection among products is made based on framework agreements or a call for tenders. If the original procurement covers both labor and materials, the selected contractor may propose a replacement product using a process tool that utilizes existing product databases.

Once the product is selected, the BIM model is enriched to a BIM product model by linking the commercial product to that design object. Now, the project parties have access through the BIM to products' all standard information. Next, the product information is enriched with process information from logistics and installation. The product, delivery batch and product individual codes will be used to track the progress of the product in the supply chain and on the construction site and to record the installation time on site. The status information and batch can be compared to production plans, and based on this, the supply chain can be controlled by responding to problems and delays or by updating the plans. It is essential that site storages are also tracked by utilizing the codes. Since similar standard products can be installed in different locations, it makes sense to maintain a separate location and status database for delivery items and product instances and link the unique product code to the model object only after installation.

Finally, the process information complements the model into a BIM process and instance model, including also supply chain and installation information. Process information can also include images, storage and installation condition information, pre-installation precision measurements, and tolerances. After the project, the data model is supplemented with operation and maintenance events and measures. At all stages, the parties should have access to the enriched product information.

DISCUSSION

This research extends the existing knowledge on PIM in construction (Nummelin et al., 2011; Berard and Karlshoej, 2012; Palos et al., 2014; Cavka et al., 2017; Lucky et al., 2019) by proposing a comprehensive PIM process for BIM-based building projects. The process presents a justified vision for utilizing product information in projects to achieve better value for the customer and to streamline construction flow in many ways. The individual solutions presented in the process are already used in advanced companies, however, the novelty of this research is in its way to present these solutions and technologies in a comprehensive manner to support smooth flow in construction project.

The study shows that the proposed process leads to many benefits for the project actors. By using a product database and data templates work of designers and procurement is systematized, and routine tasks can be automatized. Product information is better available on site, which improves flow by speeding up installation work and improves quality.

The results also indicate that by connecting product standard information with instance and process information, logistics flows become more efficient. This requires, that the deliveries are planned, and location of product is known in real time: Site production control improves when real time product delivery information can be compared to plans. Overall, enriching process and instance information increases the transparency of the construction process and enables identification of root causes for deviations during the operation and maintenance phases.

The study suggests that linking product information with BIM objects through product identification codes is a cost-efficient way to integrate product information with design models. Previous research suggested integrating producers BIM objects into the design model (Berard and Karlshoej, 2012). Our analysis indicates that linked data would make the integration easier and require less efforts both from manufacturers and project actors.

Despite of the many benefits of the streamlined and BIM-linked PIM process, the process is partly theoretical and faces practical challenges in projects. First, BIM is still not used in all projects. In those projects, some use cases, such as structured design information for procurement and access on site to space- and element-specific products, may not be possible. Without BIM, projects could still benefit from many use cases, including tools to manage product substitutes and to track material deliveries.

Secondly, to fully utilize the PIM process, material delivery plans must be complete, and efficient solutions are needed to link products to the BIM. It can be hard to decide to which object product information should be linked because all sub-components are not modelled. For example, the reinforcement and pumped concrete of wall elements are usually not modelled. In those cases, cost accounting may provide a more detailed breakdown of the final product into which to link the code of the trade product. In addition, adding products to individual objects is time consuming. Therefore, tools are needed to link all similar products at once to all the elements in the model.

The development of the comprehensive databases is also challenging. Currently, databases are often separated for MEP and other products, and they do not cover all the commercial products. Producers do not have sufficient incentives to add product information to open databases. Therefore, aligned efforts and industry-wide statements are needed to increase urgency among producers to openly provide their product information. At the same time, international standards and databased should be favoured so that global producers can publish their information in one shared database.

CONCLUSIONS

In this research, six common use cases of product information were identified during the life cycle of the construction project. In addition, solutions to enrich and import product information in the usable form for the project parties were identified. Finally, the research suggested a process model for PIM in construction projects.

The most important sub-solutions of the process are related to harmonization of product group-specific information in design, and to the product databases built according to these. Based on comprehensive and harmonized information, other solutions can be implemented, such as linking standard product information to BIM, using product and batch identification codes, and linking product process information to the BIM model.

The results and their validation with the construction professionals showed that product information is valuable not only for building owners and users, but already during the project from design to site installation. Designers could benefit from standardized ways to present product requirements. Contractors could streamline sourcing and procurement processes with use of product databases which fit with the requirements presented in the designs. Logistics and site managers can build real-time situation picture of the operations by utilizing machine-readable product information and the links between product information, delivery batches, task schedules, and designs. Overall, the enriching, linked, and real-time product information enables construction project actors to lean their operations by reducing manual work and better decision-making.

The research highlighted that systematic PIM is an essential part in the effort for lean construction. However, this research is limited to concept development and validation in FGDs. More practical research is needed to test the process and integration of the solutions. Future research could focus on the following topics:

- How to streamline procurement by standard design information and product templates?
- How to apply international product and delivery batch codes in supply chains of various construction products, including make-to-stock and project-specific products?
- How to efficiently link product standard, instance, and process information with BIM?

Further research could validate the proposed process from global product provider point of view. In addition, as information contents vary between the products, instead of project approach, it could be useful to take supply chain perspective to PIM. The supply chain perspective could reveal possibilities to learn from product information which is used, enriched and linked in the providers overall client portfolio.

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