On Construction-specific Product Structure Design and Development: the BIM Enhancement Approach

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Abstract – **The construction industry suffers from low productivity, and the Building Information Modelling (BIM) has not been successful in enhancing the productivity and the flow of information throughout highly fragmented construction projects. Hence, this study aims to facilitate consistency in information and addresses the current gaps in BIM by applying the Productization and Product Structure concept. The study follows conceptual research approach and accordingly, previous studies on productization and product structure are reviewed. The Part-Phase-Elements Matrix is proposed as a construction-specific product structure to facilitate consistency in information and enhance BIM.**

Keywords– **Productization; Product structure; Information Management; BIM; Construction**

1 Introduction

Construction industry is highly fragmented and complex and suffers from low productivity improvement [1]. Building Information Modelling (BIM) has shown some promise to assist in improving productivity [2] but remains essentially ineffective despite the potential of enhancing the collaborative way and providing relevant parties with reliable information [3]. Simultaneously, construction projects suffer from different stakeholders and suppliers using a variety of systems [4] resulting in considerable conflicts when operational integration and automation are needed [5]. Loss of relevant information and data corruption are inevitable in such circumstances. Hence, strong needs exist for a unified concept to organize and manage information, including product and process information to facilitate the integration of construction processes.

With increasing moves toward achieving the concurrent construction goal by advanced BIM [6], the construction industry is getting increasingly similar with manufacturing industry. The current situation in construction is quite alike to the experiences by complex manufacturing companies some decades ago [7]. Considerable interests exist for implementing well-established methods from the manufacturing industries to improve BIM implementation [8]. These have common goals with BIM to ensure process fluency and product data integrity among multiple systems.

Various approaches have been proposed for the purpose of improving BIM. The BIM improvement based on Product Lifecycle Management (PLM) [7], [8], adoption of Industry foundation classes (IFC) as a well-known data model standard to deliver the integrated building information [9], implementing situation based management approaches such as Last Planner [10], proposing a central information repository as a multi-disciplinary collaboration platform [11], and modularization via considering the building as a product [10]. Further, Holzer [12] suggest that BIM should be built so that standardized product data can be derived directly from the model to the existing information systems utilized in the industry, rather than transforming BIM into a construction-dedicated PLM. However, the current research is particularly deficient in construction specific information system considerations.

BIM modelling based on a standardized Product Structure (PS) has been argued to be the missing link between BIM approach and the disconnected construction processes to some extent in the literature [12]–[14]. Product structure is a consistent unit representing a physical or conceptual grouping of product components which can be easily identified and replaced [15]. Product structure is the core entity for the transmission of information across the entire life cycle of a production project system [13] that enables platform-based production, and strengthens stakeholder engagement and cooperation from product development to marketing agents [16]. Indeed, the product structure bridges the development and marketing of new products within the concept of Productization [17].

The productization concept was originally borrowed from managerial texts and mainly used in the service or software industries [18]. The concept has evolved over the years, but at a general level, productization is used in the context of creating products or services and covers all the activities required before a product is ready commercially [19]. Productization also refers to

commercial and technical modelling the offer products according to a consistent product structure [20]. Consequently, product structure plays a key role in the Productization process as a structured product information repository and makes products and related data more systematized and manageable. Despite some researchers having addressed the concept of productization in relation to modelling of products and services and the potential of product structure involving acting as a unified concept to ensure consistency of information, the context of construction industry has only been discussed to a certain extent [21]. Further work is necessary to detail the found links and to establish an equivalent central backbone structure to enhance the implementation of BIM.

This study explores the core of productization concept, and the product structure as an eminent solution to facilitate consistency in information, and hence addresses the current gaps in BIM. This is based on the argument that product structure -focused construction modelling is the missing link of the BIM approach and has potential to improve BIM performance. Addressing the gaps in BIM can support the long-term vision of improving the of product data management in the construction industry. The goal is to create a standardized concept for product information and to provide a mechanism for the effective sharing of product data between different phases of the building lifecycle. The intention is to enable flexibility in how many stakeholders can be involved in a specific project.

The above discussion can be outlined along the following research questions (RQs);

1. How does a conceptual product structure look like in a general level?
2. How can the conceptual product structure support BIM Implementation?
3. How can a specific product structure be formed to enable reliable information exchange between different stakeholders in collaboration?

This study is a conceptual research. The research methodology is presented in section 2. The Literature Review on Productization and Product Structure at the general level forms the basis to answer RQ1. Meanwhile, the literature review on construction project specifications and challenges of BIM implementation in conjunction with the conceptual product structure, offers a response to RQ2 and also supports the creation of a construction-specific product structure that responds to RQ3. Discussion and conclusion are presented in sections 4 & 5 respectively.

2 Methodology

The study follows conceptual research approach. The literature on productization and product structure are reviewed first, while seeking for different approaches to interpret concepts at a general level. A construction specific product structure is designed and developed to support BIM implementation. A three-dimensional matrix to is used to combine product structure, building product library as a structured database, and user specifications layers from various construction project phases.

3 Literature Review

3.1 Productization

The term "productization" has been used interchangeably with standardization, systemization, productivisation, industrialization and commercialization. Productization is seen to mean standardization of the elements in the offering [22] and concern all the activities before the product is ready commercially [19]. Productization is also defined as a transformation process from customer specific (low productized) to standard mass market products (high productized) offering [17], [22], in relation to which rationalization is necessary to produce deliverables from individual level tacit abstract knowledge to organization level easier to communicate knowledge [17], [23]. Productization has been seen as a delivery-oriented concept [24], which enables an optimal balance between customization and standardizationas well as the ability to make and to sell [23].

Productization refers to the conversion of custom or incidental products to standard ones [25]. Considering all the above mentioned, productization id a transformational process in which product information and materials are streamlined, systematized and standardized through replicable methods and transparent format. Productization can be seen as a process that transforms inputs into outputs, which is in line with Transformation-Flow-Value theory proposed [26] in which the production in construction is conceptualized in a way that production is one of the major concepts (transformation from inputs to outputs, as a flow to fulfil customer needs and add value). Figure 1 illustrates productization as portrayed by the literature to provide systematics for the discussion. Indeed, productization contributes through systematization and routines to both efficiency and profitability [27], covers aspects relevant to both new product development and marketing by the product-centric view. Literature on product management [14], [17], [28] further splits productization into technological and commercial perspectives. It is also claimed that productization should be split into Inbound and Outbound activities relating to capacity to produce and sell to build a harmonized development process and

avoid duplicating tasks using existing platforms and modules [18]. The outbound productization aims at improving product value for consumers and providing wider product families to satisfy consumer needs. It is believed that productization should cover both abilities to make and sell by finding a balance between standardization and customization [17] .
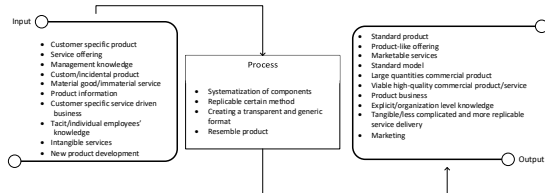

Figure 1. Productization

Evidently, the concept of productization is strongly connected to module-based product development and mass customization (MC). Modularization refers to a product and process structure in which the design elements are divided into modules with well-defined interfaces along a formal architecture [24]. Module based product development is enabler and one of the success factors for MC [29].

MC addresses distinct market requirements and promotes modularization, which can be seen as higher levels of standardization [23]. By increasing the level of productization, the clarity of the offering increases, and becomes more understandable and communicable towards customers [17]. "Successful MC products must be modularized, versatile, and constantly renewed" [29, p. 4]. This is promoted by developing modular product families for the provision of an appropriate variety of products [30] to satisfy customer needs. The concept of productization begins with the core product followed by routines.

3.2 Product Structure

A broad range of definitions for product structure exist in the academic literature [31]. The product structure term is commonly used in various fields under different terms: product architecture [15], configuration model [32], product structure tree [33]and modular product structure [30]. In a general level, product structure is defined as an organized hierarchical classification [34], [35], structural representation [36] and basis for all information of product components (characteristics, technical objects, product functions requirements) [31], [35], [36] and their assembly relationships [15], [31], [37]–[39].

Product structure is a context-dependent explanation of the product's composition from the elements and the relations between the elements in which all 'instantiated data' is managed and stored [40] to realize the product function [41] and form a consistent unit that can be easily identified and replaced [15]. Product structure captures not just the product components' assembly relationship, but also the data relationship that distinguishes them. "This data materialises as files with revisions and versions" [13, p. 11]. To ensure that product data can be handled well and that the change can be monitored and recorded, the product data should be sorted and managed according to the product structure [39].

Product Data Management (PDM) enriched by unified product structure serves as a central repository of information for process and product history and facilitates integration and data sharing among all business users dealing with products [42]. Several studies have addressed how product structure is the basis for the implementation of product data management (PDM), and fulfils the criteria of generating a manufacturing plan and schedule [39] supports managerial decision-making [39]and collaborative workflow in maintaining all design details up to date [38], so that they are dynamic and reusable.

A generic product structure is a hierarchical structure of either abstract or physical elements [43] which represent the structure of the entire product family and show which modules and part types, or classes are used in the products or a product family [31], [32]. The generic product structure offers information on possible implementations of existing templates in a wide variety of similar products [31]. Opposite of general product structure is a specific or precise product structure in which the information is only limited to a particular product. Specific/precise product structure shows the particular modules and parts, which together form the product [31]. A specific/precise product structure is a set of descriptions of components organized into a part of the hierarchy that is required to create or order the part [44].

Bill of Materials (BOM) is one of the most common product structures which identifies the parent-child relations between product components. BOM is a list of all sub-assemblies, intermediates, parts and materials that form a parent assembly and show the quality of each assembly needed to produce a complete product [45]. The terms product structure and BOM can be used interchangeably in spoken language, however, "The definition of product structure is more comprehensive" [34, p. 54]. At some point during the life of the product development, BOM is regarded as a basic filtered product structure snapshot [35].

BOM itself tends to fall into two main types; Engineering Bill of Material (EBOM) and Manufacturing Bill of Material (MBOM). EBOM is the cornerstone of the "As Designed" Product Structure that describes 'what'

the product is [46], [47], which is later converted into MBOM. MBOM, refers to 'how' the product is produced and assembled [46] by maintaining manufacturing interactions through the planning of production processes[47]. Also other product structure based BOM categories exist. According to the product structure tree EBOM and MBOM are designed automatically as requested [37]. BOM is the core part of any integration system as a means of communication during product development [48] and it is widely evidenced that the BOM related processes and implementation activities dramatically affect how an organization can run multiple systems like Computer-aided Design (CAD), Product Data Management (PDM), PLM, and (Enterprise Resource Planning) ERP [42].

Product structure can encompass and store various kinds of product information. It is viewed that the product structure description data can be summarized into natural attributes (product and part names, ID, size, material, weight, and origin) and the relevance between the components (father-child relationship between products and parts) [49]. It is also argued that product structure information consisting of product structure decomposition, part ratios and outgoing fractions, help to frame the limits of a system and to model and analyse the subsystems, which can be retrieved from BOM and disassembly BOM [50]. Some academics also suggest an extra node between the product and part nodes and refer to modules [31] or components [37] that can be common or alternative/optional components equipped with configuration rules [43].

3.3 Construction Projects Context

3.3.1 BIM in Construction Project Context

Construction projects have certain properties that complicate their management, to name a few, quite volatile planning environment, evolving production locations, highly fragmented and extremely multidisciplinary non-linear work processes, spatial restrictions, and specific regulations [13]. These properties place difficulties on the construction projects regarding cooperation, accurate exchange of knowledge, and incorporation of various stakeholders.

It is widely acknowledged how the collaboration of numerous multidisciplinary project members through continuous, accurate and real time information sharing, play a vital role in overcoming these difficulties [51]. The ambiguity that surrounds the definition, business value and purpose of BIM impede a common understanding of BIM implementation between stakeholders [52]. Accordingly, the major issue is that "BIM is a powerful but complex technology" [53, p. 321].

The challenges of BIM implementation have been widely discussed in literature. Lack of defined standards

and technically integration requirements and management of outcomes as the main barriers to BIM use [2]. BIM implementation faces challenges like the need for a well-design transactional structure and practical strategies for integration and the exchange of information among involved parties, a need for well-developed guidelines, a need for someone to be responsible for the distribution of operational development, cost and to identify a suitable time for the engagement of stakeholders in different segments to exchange the information [3]. Therefore, the challenges to the implementation of BIM with regard to the scope of this study needed to be examined with the capabilities of the construction-specific product structure. In this regard Section 4 presents debate.

3.3.2 Product Structure in Construction Project Context

Product structure concept relating to construction projects follow the general product structure logic in terms of structure and context. A construction project and the related productization mechanism, could be split into capacity to produce (Inbound) and sell (Outbound) activities as proposed by [17]. Harkonen et al. (2018) further modelled the technical product portfolio and commercial product portfolio in the construction project context by simultaneously relating to the development and sales capability activities.

The product structures are generated during the design phase [40], where all necessary stakeholders should be involved to design the product structure according to their requirements [38]. The requirements help to clarify what the product must do, or the qualities of the product. These requirements tend to fall in three categories: functional requirements referring to things the product must do, non-functional requirements referring to qualities the product must have, and constrains referring to context specific limitations that shape the requirements [54]. These requirements must be gathered and categorized according to the customer needs, regional business resources, and context-specific constraints [15]. Nevertheless, product structure might be overloaded with a wide variety of requirements and become difficult to handle should the large number of stakeholders and different domains be considered, meaning all those involved in construction projects. Therefore, also considering the capacity of product structure is vital while attempting to satisfy the various user criteria and the needs of different construction project phases. An unified product structure should be a tradeoff between individual requirements of various stakeholders (differentiation) and keeping standardization and commonality product's components [55].

The next preliminary concept to consider is a

database for potential technical objects that support is among them [2]. General product structure determination proposed by [36] involves arranging functional elements, mapping them to physical components, and defining interface specifications among components, and a technical objects. It is also worth noting that in order to make the database functional, the technical objects library needs to be hierarchically organized in a standard way. Feature templates have been proposed as a database to consist of well-formed, predefined CAD features, attribute aggregations, and constraints enhanced with engineering information and reusable geometric elements [31]. Yet the function models may not have enough structure and integration might be necessary. Accordingly, a construction classification system can be used to provide standardized technical objects, which are coded and organized hierarchically. There are several "construction classification systems" available based on different logics, but the main purpose in all is to classify building artefacts to support reliable information exchange [56]

Comparison between alternative construction classification systems have been investigated, including OmniClass, MasterFormat, UniFormat and Uniclass [57]. The UniFormat classification system is used in this study, as its purpose is to "enhance reporting of design program information, especially for preliminary project descriptions and performance specifications, and provide a basis for systematic filing information for facility management, drawing details, BIM objects, and construction market data" [58, p. 1]. This is in line with objectives of this paper. In this classification system, the building elements are hierarchically grouped into three levels of major group elements, group elements, and individual elements [59]. These three dimensions need to be acknowledged simultaneously to ensure coherent, reliable and structured knowledge to be shared by various stakeholders in the construction project life cycle phases.

A Part Template Matrix has been proposed for a generic product structure, which nicely visualizes dependencies and affiliations between feature templates and product structure [31]. Inspired by that, this study aims to enhance the proposed matrix using standardized and structured database as the source of all applicable individual element level building artefacts.

4   Results and Discussion

4.1   Conceptual Product structure and BIM

The content and structure of the product structure have been discussed in the literature based on hierarchical elements and also on the basis of information within each element. Figure 2 depicts a product structure

from the hierarchical elements of the product (Left) and their respective units of information (right). The illustration is inspired by the previous research regrading product structure in general level.

The product part-of hierarchy structure starts with the product family including different products and displays alternate modules and component forms (parts) that could potentially be used in the products, or the product family. Information units correspond to elements of the product structure illustrated in on the right side of figure 2. Information of possible variety of products (Product Data layer) is stored as a generic product structure which includes several different specific products structures (BOM). Next level is the assembly process layer that includes a collection of component descriptions required to build or order a part. In this level, specific EBOM and MBOM describes 'what' the product is and 'how' the product is produced and assembled. Detailed information of the parts is stored within the elements layer to specify the characteristics used for grouping or separating.

The findings indicate that a product structure consist of comprehensive information regarding product and production process with a clear structure of relations between detail information. Meanwhile, information can be tracked and reused from product data, process and elements layer of product structure. The centralized and standardized product structure makes it accessible and easy to follow as a consistent information unit for all the stakeholders involved in the lifecycle of construction projects. In short, a product structure with a well-designed structure can provide a platform for continuous, accurate and real-time information that can be used in collaboration with numerous stakeholders.

Regarding "BIM" implementation, the mentioned gaps in could be well addressed with the potential of the product structure discussed in literature promoting standardization, collaborative exchange of reliable information and integration of multidisciplinary stakeholders. The flow of information about elements and their relationship, production process, specific product and product family will be available via a product structure.
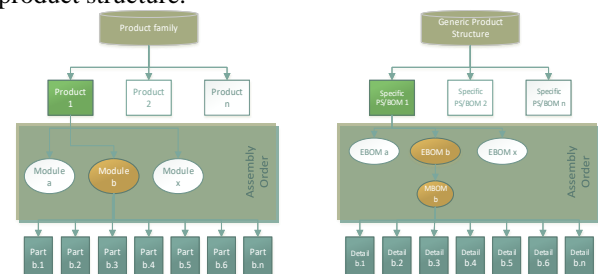

Figure 2. Product Structure from hierarchical elements of the product (Left) and their respective units of information (right).

4.2 Construction Specific Product Structure

The construction projects' specifications are considered to develop a construction specific product structure, since the product structure is a context-specific phenomenon itself that can be interpreted differently through the project life cycle with various disciplines and stakeholders involved in the project.

In this regard, the findings indicate that the product structure could be developed to be used from both technical and commercial standpoints. The conceptually illustrated product structure (Figure 2) was developed to be used for technical and commercial purposes. Involvement of stakeholders and related well-defined requirements within the early stages of construction projects enhance product structure functionality. Hierarchically structured and standard library of building objects further facilitate efficient information exchange among stakeholders.

Accordingly, the product structure is enriched first by the standard construction object library which consist three layer of details including major group elements, group elements, and individual elements. These three levels may well correspond to product structure hierarchy levels of product, modules, and parts. A Matrix based model is used to explain corresponding dimensions and their interactions.

Using a standardized and structured database as the source of all applicable individual element level building artefacts in bottom of product structure will enhance collaborative exchange of reliable information and integration of multidisciplinary stakeholders. This approach provides a basis for systematic flow of information across project and add an appropriate classification of elements.
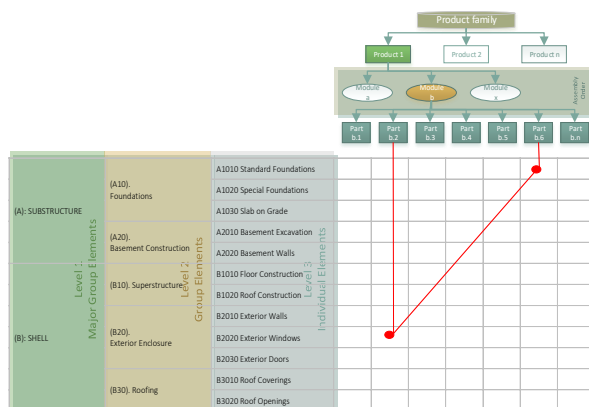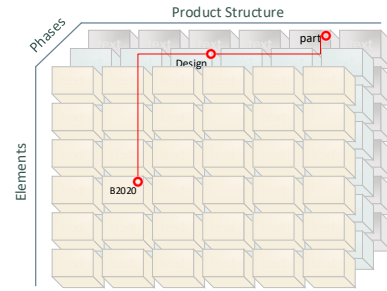

Figure 3. Part-Elements Matrix

Figure 4. The Part-Phase-Elements Matrix

So far, Part-Elements Matrix is able to integrate PS and library elements. To make the Part-Elements Matrix usable for involved parties acros different stages of the project, third dimension is needed to illustrate the potential inclusion of unlimited users from different disciplines within the construction phases (Figure 4). The addition of user dimension, in other words, allows the collaborative use of the proposed Part-Elements Matrix. The proposed matrix has added new dimensions called Phase Layer. As a result, the 3-dimentional Part-Phase-Elements Matrix has formed demonstrating the relationship between the parts, elements, and users. The Part-Phase-Elements Matrix has Part-Elements Matrix capacities as a basis and allows stakeholder engagement to enhance BIM as well.

The Part-Phase-Elements Matrix shows the relationship between the part and the correlated elements that exist in the object library. In the meantime, the phases layer indicates that the stakeholder involved in the second phase of the project (design) is the corresponding user. In the example given in figure 4, the element no. B2020 related to Part (x) from PS, is used by a user from Design phase. This type of relational information. The proposed Part-Phase-Elements Matrix has the potential to facilitate consistency in information and enhance BIM as a construction-specific product structure.

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