PRODUCT MODULARIZATION: CASE STUDIES FROM CONSTRUCTION INDUSTRIES

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Abstract: *Across all industries companies benefit from product standardization and product modularization in order to automate sales and production processes, and construction industry is no exception. Product modularization is normally the pre-requirement to the automation in both sales and production. The literature is lacking guidelines and examples to discuss both theory and practice of product modularization in construction industry. In this study, we discuss two main product modularization strategies and investigate how and where they were applied in different construction companies. This research benefits from comparative case studies research. The gathered empirical data and the results from industrial expert interviews can then be used as guidelines for the companies to analyze how, when and where to use different product modularization techniques and what the gained benefits and challenges can be.*

Key Words: ***Mass Customization, Construction Industry, Product modularization, Interviews, Comparative Analysis***

1. INTRODUCTION

One of the solutions to the challenges in the construction industry is known to be standardization which facilitates prefabrication of an increasing number of buildings components, allowing, in return for industrialization of the building process to continue to widen in scope [1]. In this context, standardization means transforming traditional craftsmanship production to machine-based modularized production [2]. Standardization and automation reduce waste throughout the construction activities performed by various stakeholders [3]. The principles of mass customization allow for offering individual products through standardized production; thus keeping costs down while increasing quality and customer satisfaction [2]. Multiproduct development based on modular architectures enables companies to recycle and reuse knowledge, concepts, components and processes, thereby creating opportunities to minimize the costs while satisfying a wider and more diverse range of customer needs [4], [5]. The building is seen as a set of major systems or component like external walls, roofs, interior partitions, floors, structural elements and building services components, etc., where enterprises perform between off-site production of products and components and on-site assembly to contribute to the different processes in a construction project [6].

In this paper, we investigate two specific strategies that we argue are unique to the Architecture, Engineering and Construction (AEC) industry. Through the first strategy – the top-down approach – the whole system is first broken down into a few main components, then into smaller sub-components. This process will continue to the point that a satisfactory level of understanding is gained [2], [7]. For example, in using a top-down approach for constructing a house, the focus would be on the large-sized building components each of which are formed of several sub-components and materials, but and not too much on details. The second strategy – the bottom-up approach – first examines the smallest parts and elements and then combines them into larger components or modules [2], [7]. An example of this could be a detailed description of a lighting system inside a house which should be explained in details. Then all these detailed elements will be combined to the whole concept of the house – or any other building – contributing to its whole lighting system as one of many components of its Monitoring and evaluation (M&E) systems. Top-down learning proceeds from explicit to implicit knowledge, while bottom-up learning goes on from implicit to explicit knowledge [8].

Despite various studies on product modularization and customization where the use of Building Information Modelling (BIM) has also been advocated as a facilitator [9], [10], there still are areas in need of further investigation. One of the relevant questions will be, for instance where product modularization can be deployed in order to facilitate automation in the AEC industry. Also a reasonable number of general research projects on product modularization exist [11]–[13], but studies on how, when and where to apply product modularization techniques are few and far between especially when it comes to empirical, pragmatic or applied research.

A promising and feasible solution seems to be gradual product modularization of parts or segments of a construction project in order to minimize the scale frequency and severity of economic risks of the project [14]. This gradual implementation strategy can be achieved in two ways: through a top-down or a bottom-up strategy both of which are somewhat in use in the AEC industry, to certain extents, but have not yet been articulated, analyzed or synthetized systematically in order then to be generalized as an established strategy throughout the AEC industry. In this paper, we will look at the case studies where AEC companies have been intuitively benefiting from top-down or bottom-up product modularization approaches building upon on their long-established and invaluable professional expertise. We will test the following research question:

How, when and where are top-down and bottom-up product modularization approaches applied in the AEC industry and what are the perceived benefits and challenges of each?

2. RESEARCH METHOD

This study uses inductive case study research approach to help provide the opportunity of comparing different product modularization theories and observations from empirical data [15], [16]. Besides, the semi-structured interviews help to collect data from the experts in the case companies. Moreover, through this method data are collected from different large organizations, using a qualitative approach which facilitates obtaining proportionate level of details. Two case organizations were selected with common factors. The multiple cases are the product modularization projects on different products in the selected companies. This case study methodology is designed as a qualitative comparative analysis method based on multiple data sources: content analysis (of both written documents and drawings) of selected projects, workshops, interviews and participant observations. The particular focus was on the practical implementation of the top-down and bottom-up strategies. Each interview was semi-structured, to allow for the flexibility of gathering additional insight throughout the interview process. This paper presents the preliminary results of the pilot interviews. The pilot study is test-run to find out if the questions are correct, understood as intended and understood uniformly across the board.

Two case companies were selected where common factors of: 1) A process producing complex and highly engineered building elements, 2) the use of bottom-up or top-down product modularization approaches for one of their products, 3) potential access to management and senior experts at the companies, 4) located in Scandinavian geographical location, were present. Typically, the primary source of data in this study was qualitative data collection through interviews, and other sources of data e.g. personal observation, informal conversations, attending the meetings and review the archival sources were also utilized as appropriate [17].

3. LITERATURE REVIEW

3.1. Mass customization in construction industry

With the development of lean production, another paradigm has slowly emerged as "mass customization" [18]. Despite other industries, the building industry has been slow in adopting this new paradigm [19]. Mass customization is defined as the low-cost, high-volume, efficient production of personalized products which meet individual needs and requirements of each customer based on their order [20], [21]. Some of the substantial challenges facing the construction industry in its post mass production paradigm has been the market size, the stakeholders management, as well as the challenges of business model and business case for personalized end-products [9]. Few years ago, an approach has been proposed based on mass customization principles with a focus on integrated system delivery using computers [19]. It is however widely believed that, the introduction of BIM – whether as a tool, an environment or a platform – can facilitate mass customization in the construction industry [22].

3.2. Product modularization

Product modularity is considered to be a key enabler of mass customization which allows production of modules and components in volumes. Product modularization minimizes redundant effort and all kinds of waste [12]. Introducing structure and product modularization in an Engineer-to-Order enterprise also opens up new higher-volume market segments down-market, potential new markets in sub-systems, and also removes much of the potential risks associated with bidding for business [12]. Baldwin and Clark [11] define three distinct characteristics of a product platform, a modular architecture, the interfaces and the standards, which form design rules to which the modules conform.

Product design requires time, and therefore, a natural way to introduce modular products would be in the same cycle as new product development and new product family launches [13]. Thus, the most important area for product modularization is the interfaces between the components rather than the components themselves.

When trying to understand a complex system, two different approaches are normally used as top-down and bottom-up [7]. Through the top-down approach, the whole system is first divided into a few main components. These components are then divided into smaller components, and so on until a satisfactory understanding of the system or the process is gained. On the other hand, the bottom-up approach, first examines the smallest parts and components and then combines them into larger components or parts of the product until a satisfactory understanding is achieved. Level of details are normally higher in the bottom-up approach, which starts with the details of the product. Top-down, on the other hand, is more conceptual which means all different components are not speculated on in details – only the large parts. Top-down is normally for very big complicated projects and bottom-up works better for smaller projects [2], [14].

Conclusively, in order to modularize a product, one of the top-down or bottom-up approaches are used. Table 1 summarizes some of the literature using case projects to elaborate on modularization approaches including top-down and bottom-up strategies where the research and case studies from both construction and ETO industries are incorporated.

Table 1. *Few reserch in construction companies using top-down or bottom-up approaches for modularization and automation*

References	Approach	Explanations
(Bonev, Wörösch, & Hvam, 2014) [23]	Bottom-up	The higher level of commonality along the entire lifecycle of the building project directs to additional reductions of lead times within production and on-site assembly. The additional benefits from using the platforms can be exemplified on the low-end system, where the standardized production processes report a 30-50 per cent lead time reduction. The
(Thuesen & Hvam, 2013) [24]	Bottom-up	A framework is developed in order to analyses a specific case on system deliverances – the application of the bottom-up modularization approach. Findings from the development and production of the installation shaft show that system deliveries represent a promising strategy for moving from red ocean competitive environment with the predominant cost+ business model, to a blue ocean situation in which the competition emerges in the constant pursue of value creation and cost reduction.
(Kudsk, Hvam, & Thuesen, 2013) [25]	Bottom-up	The aim of this research is to discover how configuration systems can support a product's design process when a high degree of variation is required and a very open or endless space exists for possible configurations.
(Kudsk, Hvam, Thuesen, et al., 2013) [2]	Top-down	These solutions were identified and their relations mapped using a Product Variant Master (PVM). When a satisfactory overview was achieved of the major technical solutions, a configuration system was made. Such a system is often used to communicate findings from the PVM to the user. Through the work of constructing the PVM and the configuration system, it was found that a great potential exists for implementation. Based on the findings and experiences gathered throughout the process, the conclusion is that the principles of mass customization are best used in the construction industry if used with a top-down perspective.
(Kudsk, Grønvold, et al., 2013) [14]	Bottom-up	Case company 1 standardized their products (balconies) by studying the products they previously built and constructing solution spaces in which a configured balcony can be constructed. The information gathered from studying these balconies was then put into a Product Variant Master, so that an overview of the product was achieved. All the information gathered was put into a configurator in order to guide the entire construction process. Case company 2, developed a prefabricated and configurable installation shaft along with several partners. Today, they supplies this prefabricated installation shaft to construction projects both inside and outside the company
(Jensen, Olofsson, & Johnsson, 2012) [26]	Bottom-up	The team in the case company decided to develop a modularized system where module variants of building parts, such as walls and slabs, were designed using slot modularity. These modules can be configured to fit the architectural design of the building using cut-to-fit parameterization
(Thuesen & Hvam, 2011)[27]	Top-down	The research analyzed the implementation of a platform for housing projects through a successful case on modern methods of construction featuring efficient on-site construction. Through continuous development, the platform has been carefully designed to suit a carefully selected market – optimizing cost and value. Based on the platform, the company has managed to create a high-quality product at low cost. In fact, they have managed to reduce costs by more than 30 per cent, enabling the company to sell houses to people that normally would not be able to afford a house of their own

4. RESULTS

The notion of an element, a component and an end-product in the building industry is not similar to what it is in the manufacturing industry. This means that the shared components may be produced in a significantly lower number than what it is meant in other industries to be able to justify the economies of scale [28]. While there were also some other approaches in creating the customizability of products, modularity was considered to be the most important enabler among the interviewed companies.

On large-scale projects, this bottom up approach does not entirely replace the traditional processes, but complements it with an increased level of information from the very beginning. In this sense, we partially substitute the traditional concept of design optimization as a linear process, with a new model of design workflow based on the parallel development of the actual idea and its feasibility [29].

The results of the interviews with two of the selected cases illustrated interesting results in Table 2. Case 1 is a large sized AEC company building full houses in different types and sizes. It is a Swedish construction company with activities across Scandinavia as well as the Baltic countries, northern Germany, Russia and Poland. In Sweden, the regional department of the case company carried out a project to construct prefabricated house elements ready to be assembled after being shipped to the construction site. In this project, they have benefitted from a top-down approach.

Case 2 is a medium sized AEC company producing balconies for different building sizes. The case company is a Danish construction SME which controls a network of a production lines and manufactures customized balconies. They have used a bottom-up approach to modularize the balconies and standardize its manufacture. The balconies comprise multipart products that have been standardized through the interfaces within the product. Altan.dk does not focus only on the physical product – the balcony – but on the entire process of installation, customer service and support throughout their products lifespan.

5. DISCUSSION AND CONCLUSIONS

The two cases discussed help investigate how, when and where the product modularization methods are used in two different companies in the AEC industry. This is done by focusing on Top-down and Bottom-up approaches. It seems that each of the product modularization methods have some specific benefits. The company with top-down approach concentrates mainly on full end-product in order to have a holistic overview of the re-usable solutions. The company using bottom-up approach on the other hand, focuses on smaller components of the buildings; the balconies. This company aims to have a detailed analysis of a less complex components to be fully able to automate the process.

Top-down approach helps the team have a conceptual overview of the whole process and the relations between the products. It proves to be a helpful product modularization tool in complex products with numerous components in order to avoid being entangled in unnecessary level of details. Bottom-up approach is used for less complicated products to establish the details by describing one specialized product in order to optimize a smaller part of a construction project, eliminating the other parts which are not directly relevant. The companies using bottom-up approach gain a substantial amount of specialized knowledge which needs to be handled effectively.

The study is a proof-of-concept which only recruits two case companies. The number of cases can be increased to improve on the validity and reliability. The interviews could be structured in terms of different questions. For the future studies, different specific factors can be discussed for each of the product modularization techniques.

Table 2. *The results for case 1 and case 2: observations and interviews*

Cases	**Applied approach**	**Interpretations**
Case 1	Top-down	These solutions were identified and their relations were mapped using a Product Variant Master (PVM) [30] in a project to modularize a full house for automating the sales process in the future. Based on the findings and the feedback gathered throughout the process, the conclusion is that the principles of mass customization are best used in the construction industry if used with a top-down perspective. There is a demand, especially regarding the architectural aspects such as the geometry of design, the perceived façade expression, or the ‘look’ of the building. These subjective demands are hard to grasp, and therefore product modularization based on equations and logical statements make these aspects difficult to implement. Top-down product modularization technique helped this company develop a holistic architecture and system solutions and capitalize on re-usable solutions. They reported that top-down strategy helped them analyze the large-scale market rather than focusing on individual or niche one-off markets.
Case 2	Bottom-up	The chosen company have standardized their specific components (balconies) by studying the balconies they had previously built and constructing ‘solution spaces’ within which a configured balcony can be constructed. Through the bottom-up approach, the smallest parts and elements are examined first and then combined into larger components; the mid-sized parts of the final product. The information gathered from studying these balconies was then put into a Product Variant Master (PVM), so that an overview of the product can be achieved. The cases show that a number of benefits can be gained through implementation of modules in the construction industry by focusing on a bottom-up strategy, and by describing one specific part in great details. This was done in order to optimize a smaller part of a product, isolating the unnecessary rest. In this way, the company have gained a substantial amount of data and been able to handle it. The results suggest that the focus will be more on the individual or personalized markets.

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