Product Modularization in the Architecture, Engineering and Construction (AEC) Industry

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Abstract

All industries benefit from product standardization and modularization in order to automate the sales and production processes. The Architecture, Engineering and Construction (AEC) industry is lagging behind due to the challenges it is faces with compared to other industries. The literature discusses how to apply modularization in construction industries, however, what seems to still be missing are guidelines and case examples for both researchers and practitioners. In this study, we discuss two main modularization strategies and investigate how and where they were applied in different construction companies. This research benefits from comparative case studies research in order to make deductions from different empirical data to draw a logically plausible conclusion. The gathered empirical data and the results from industrial expert interviews can then be used as a guidelines for the companies to analyze how and where to use different modularization techniques and what are the gained benefits and challenges.

Keywords
Case study research, Construction industry, Product Architecture, Product modularization, Product standardization,

Purpose
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 (Nissen, 1972). In this context standardization means transforming traditional craftsmanship production to machine-based modularized production (Kudsk, Hvam, et al., 2013). Standardization and automation reduce waste throughout the construction activities performed by various stakeholders (Peterson et al., 2011). The principles of mass customization allow for offering individual products through standardized production; thus keeping costs down while increasing quality and customer satisfaction (Kudsk, Hvam, et al., 2013). 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 (Miller, 2001; Ulrich, 1995). The building is seen as a set of major systems or component like external walls, roofs, interior partitions, floors and all structural

and M&E components such foundations, HVAC systems, etc., where enterprises mutually between off-site production of products and components and on-site assembly to contribute to the different processes in a construction project (Lachimpadi et al., 2012).

In this paper, we focus on two specific strategies which we argue are unique to the 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 (Kudsk, Hvam, et al., 2013; Sun and Zhang, 2004). For example, in using a top-down approach for constructing a house, the focus would be on the big building components each of which 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 (Kudsk, Hvam, et al., 2013; Sun and Zhang, 2004). An example of this could be a detailed description of the lighting system inside the house which should be explained in details. Then all these detailed elements will be combined to the whole concept of the house forming its whole lighting system as one of the components of its M&E systems. Top-down learning proceeds from explicit to implicit knowledge, while bottom-up learning goes on from implicit to explicit knowledge (Sun et al., 2001).

Despite various studies on modularization, customization where the use of BIM has also been advocated as a facilitator (Farr et al., 2014; Hartmann et al., 2012), there still are areas in need of further investigation, for instance where product modularization can be deployed in order to facilitate process automation in the AEC industry. Also various researches on modularization in general exist (Baldwin and Clark, 2000; Gelman et al., 2005; Mäkipää et al., 2010), but studies on how and where to apply the modularization techniques in the AEC industry are few and far between especially when it comes to empirical or pragmatic research.

A promising and feasible solution seems to be gradual implementation through modularization of parts or segments of a construction project in order to minimize the scale frequency and severity of economic risks of the project (Kudsk, Grønvold, et al., 2013). This gradual implementation strategy can be achieved in two ways; through either a top-down or a bottom-up strategy which both are somewhat in use in the AEC industry but not systematically articulated, analyzed or synthetized to then be generalized as a commonly 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 modularization approaches building upon on their long-established and invaluable professional expertise. We will test the following working hypothesis:
How and where are Top-down and Bottom-up modularization approach applied in the AEC industry and what are the gained benefits and perceived challenges of each?

Research Method

This study uses case study research approach because it can provide the opportunity of comparing different theories and observations from empirical data (McCutcheon and Meredith, 1993; Van de Ven, 1989). Moreover, through this method utilized in this study empirical data are collected from different large organizations, a qualitative approach provides good opportunities for obtaining the correct level of detailed information. Five case organizations were selected with common factors. The multiple cases are the modularization projects on different product =in the selected companies. This case study methodology is designed as a qualitative comparative explanatory method which is built upon multiple units of analyses acquired using different data collection instruments and 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, including the modularization methods for platform design. 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.

Findings

The notion of a component 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 (Piroozfar and Larsen, 2010).

The results of the interviews with two of the selected cases illustrated interesting results.

Table 1 comparison of RUP and Scrum for general IT projects management

Cases	**Applied approach**	**Interpretations**
Case 1	Top-down	These solutions were identified and their relations were mapped using a Product Variant Master (PVM) (Hvam et al., 2008) 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 are demands, 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 modularization based on equations and logical statements make these aspects difficult to implement. Top-down modularization technique let this company think in terms of holistic architectural and system solutions and develop re-usable solutions. They reported that Top-down strategy helped them to analyze the big scale market rather than focusing on individuals 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 construction, isolating the unnecessary rest. In this way, the companies have gained a substantial amount of information 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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Biographies

Sara Shafiee is a postdoctoral research fellow at the Technical University of Denmark, Department of Mechanical Engineering. She has the experience of working in Engineer-To-Order companies as IT Project Manager and Senior Business Consultant and developing and maintaining more than 10 Product Configuration Systems. Her research is focused on Product Configuration systems challenges for complicated highly engineered products. She has a series of papers about product configuration projects scoping, documentation and modeling, knowledge management, IT tools integrations in international conferences and journals.

Poorang Piroozfar is an architect, a principal lecturer (associate professor) in architectural technology, the academic subject lead for the built environment and construction and the director of the Built Environment Research Group (BERG) at School of Environment and Technology, University of Brighton, UK. His research specialization is in mass customization and personalization in the built environment, architecture and construction. His other research interests span over the application of advanced technologies in the AEC industry – including AI, Machine Learning, IoT, Gamification, BIM, BEM/BES, AR/VR, UAV, and Robotics in the AEC industry – Integrated Design, Expert Systems, the dialogical interaction between theory and practice, and design research.

Lars Hvam is Professor at the Technical University of Denmark. He has been working on product configuration for more than 15 years as a teacher, a researcher and as consultant for more than 15 configuration projects in large industrial companies. He has supervised eight Ph.D. projects on the construction and application of configuration systems and has been the project lead for four large research projects on product configuration. Lars Hvam is also the founder and current chairman of the Product Modelling Association (www.productmodels.org), whose aim is to disseminate knowledge of the possibilities offered by product configuration.