Developing Products in Product Platforms in the AEC Industry

P. Jensen[1], T. Olofsson[2], E. Smiding[3] and R. Gerth[4]

[1]Tyréns AB, 118 86 Stockholm, Luleå University of Technology, 971 87 Luleå, Sweden; patrik.jensen@tyrens.se
[2]Luleå University of Technology, 971 87 Luleå, Sweden; thomas.olofsson@ltu.se
[3]Tyréns AB, 118 86 Stockholm, Sweden; erik.smiding@tyrens.se
[4]Tyréns AB, 118 86 Stockholm, Sweden; robert.gerth@tyrens.se

ABSTRACT

A 5-step method for developing configurable "products in product" platforms to be used in an engineer-to-order (ETO) design process is proposed. The idea is based on the transformation of typical product architectures into modular design platforms where standard and variant modules are identified and developed. The platform modules can then be configured and combined using traditional design methods to meet the project specific requirements in the design process. Based on 1193 project designs, several configurable "products in product" were identified and developed in a real case study using the proposed method.

INTRODUCTION

Mistakes made in the traditional engineer-to-order (ETO) product design process generate waste downstream of the construction process (Lopez and Love 2012). The short-term interactions between loosely coupled partners in the construction supply chain (Dubois and Gadde 2002; Segerstedt and Olofsson, 2010) also provide poor incentives for the development of practices, methods and designs that can be reused between disciplines, partners and projects (Mossman, 2009).

In traditional manufacturing, the standardization of components and continuous improvements to the production processes have been ways to increase efficiency and lower costs (Winch 2003). Therefore, some researchers have proposed that the construction industry can learn from the methods and procedures applied in manufacturing industries (Gerth et al. 2013). However, a serious obstacle for the introduction of increasingly industrialized processes is the constraints imposed by a standardized design in a traditional engineer-to-order process governed by customer specifications. This can lead to ad hoc customizations which seriously impact the cost of realization (Malmgren et al. 2010; Segerstedt and Olofsson 2010).

Modular product architecture has the potential to increase product variety with a high degree of commonality (Robertson and Ulrich 1998). The creation of modular product architecture has thus been suggested as a solution to increase standardization and performance within the AEC industry (Gerth et al.,2013; Bertelsen 2005). Historically, most modularization methods within the manufacturing industry have focused on defining standard modules and variants of modules that can be combined into different product variants (e.g. Holmqvist and Persson 2003; Erixon 1998). In construction, it is assumed that most products cannot be modular in design because of the perception of uniqueness in each project. The development of new product architectures for each project prohibits knowledge transfer between projects and trades (Love et al. 2010; Lam and Wong 2009).

So far, the use of configurable and modular product architectures in construction have been limited (Winch 2003). Therefore, the objective of this paper is to investigate how principals and methods from the manufacturing sector, relating to modularization and product architectures, can be adapted to the AEC industry.

THEORY

Product architecture describes the arrangements of functional elements, their mapping to physical components and the specification of interfaces between the interacting components (Ulrich 1995). The product architecture can be modular or integral to differing degrees. A modular architecture has a one-to-one mapping between functional elements and physical components with corresponding de-coupled component interfaces (Kim and Suh 1991; Ulrich 1995). An integral architecture has a more complex mapping between functional elements, physical components and interfaces between components, and is more often found in one-of-a-kind products (Ulrich 1995). A modular architecture provides opportunities to develop product platforms based on modules. Meyer and Lehnerd (1997:11) defined product platforms as “A set of subsystems and interfaces developed to form a common structure from which a stream of derivative products can be efficiently developed and produced”. A commonality index is often used to measure the number of common components/modules in a product architecture relative to the total components used (Collier 1981).

Modularization, the development of modular products, is defined by Erixon (1998:58) as “decomposition of a product into building blocks (modules) with specified interfaces, driven by company-specific reasons”. A modularized product consists of standard and variant modules. A standard module is defined as a module that is included in all product variants within a product family, while a variant module is available in different varieties and is included only in some of the products of the same family (Stake 1999). There are many drivers for a modular architecture such as higher commonality of parts, standardized production, shorter lead time in development and production, and the potential for incremental product development. Modularization of product architecture can also be seen as the making of “products in product” or “factories in factory” Erixon (1998:129). The customization or configuration of a modularized product is normally supported by a configurator. According to Hvam et al. (2008), the configurators are based on a modular design.

A number of theories have been suggested to help develop configurable product platforms; a comprehensive list of modularization methods and tools can be found in Holmqvist and Persson (2003) as well as in Farrell and Simpson (2003). While most research concerns the configuration of standard and variant modules to custom orders in assemble-to-order and make-to-order supply chains, there has been little investigation of how modularization can support the design process in an ETO construction process.

Jansson et al. (2013) concluded that platform theories from manufacturing “cannot be applied straightforwardly by ETO companies” but need to be complemented with support for traditional design when project requirements meet platform parameters in an ETO design process. Jensen et al. (2013) discussed the transformation of traditional ETO product design into a more modular product architecture, where the platform part contains standard and variant modules that can be configured and combined with traditional engineering design of the remaining unique parts of the product.

DEVELOPMENT OF CONFIGURABLE "PRODUCTS IN PRODUCT" PLATFORMS

The proposed method for developing configurable product platforms to be used in the design of construction products is based on access to an ETO company's traditional designs. The idea is based on the transformation of typical product architectures into modular design platforms where standard and variant modules are identified and developed. The platform modules can then be configured and combined with traditional design methods to meet the project specific requirements in the ETO process. The following steps are proposed:

1. Selection of a "product family". The products within a family in the selection should have a similar product structure such as multistory buildings, single family houses, concrete bridges etc.
2. The definition of a generic product architecture for the selected product family. The generic product architecture works as a "template" and guides how the product family is structured through modularization levels and module candidates.
3. Definition of the functional requirements for each identified module candidate in order to identify the design of interfaces.
4. Categorization of modules into the three types standard, variant and unique, depending on the commonalities found in traditional designs of the module candidate based on the return on investment estimations (ROI).
5. Development of configurators for the identified modules.

An experienced designer of the family of products needs to be engaged in the definition of the template product architecture. The template product architecture, product level breakdown and identification of module candidates need to be validated, for instance, by interviewing and surveying designers and project leaders who have been involved in previous projects in the ETO company. The definition of functional requirements and the coupling to the physical design are needed to determine how the interfaces must be designed. Depending on the volumes of categorized modules defined in step 4, the ROI estimates of the development of the configurators can be made. The main driver for the development of modules and module configurators is an ROI over a short length of time. The last step includes the actual development of the configurator based on:

- Parametric definition of the module (height/length/thickness/ratios etc.)
- The input/output to/from the configurator such as geometry, CAD models, bill of materials, structural design calculations etc.
- Potential constraints from a structural, production or supply chain point of view.

RESEARCH APPROACH

In order to test and validate the proposed method of developing configurable “products in product”, the authors of this paper have been involved with an ETO consultancy firm, responsible for the development of module configurators. Therefore, the research process has been carried out as an action research process (cf. Vinten 1994). The purpose of this research is to analyze whether the proposed method is appropriate in practice and can create configurable product architecture for typical construction products (Patton and Appelbaum 2003). Deep qualitative empirical data are required to validate each step of the method, which means that the use of case studies is a suitable validation approach (Eisenhardt and Graebner 2007). Therefore, the method was tested with a real case of an ETO engineering consultancy firm to complete the empirical validation of the method.

CASE STUDY

The engineering consultancy firm studied delivers design solutions for all product types and contractors in Sweden. Recently, the company put together a multi-disciplinary team to develop modular product structures where parts of the structure i.e. “products in product” can be configured using configurators. In order to analyze and structure the architecture for the product family of buildings, data from the company's previous projects were analyzed. Since the business management system does not contain information regarding the projects’ inherent technical solutions, a total of 70 project managers were surveyed to specify the design for each of the projects carried out between 2010 and 2012. The response rate was 72% and resulted in 1193 projects being analyzed and used as the basis for continued development in accordance with the proposed method.

1. Selection of product family. The first step includes identifying the right product for development. As stated by Cooper et al. (1999:333): “Portfolio management is about making strategic choices – which markets, products, and technologies our business will invest in”. The selection included an evaluation of which products are most commonly used by the firm, but also those “products in the product” that would be easy to implement and use. In the case study, the product family of buildings was selected.

2. Defining the product architecture for the selected product family. Based on the 1193 project designs, a template product architecture that worked as a proposal for how the product platform could be designed was developed. Figure 1 shows the product architecture and decomposition of the product family of buildings. In 28% of all projects examined, the design of foundations and groundwork was included. The team started the modularization work on the ground level because it was the second-most common type of design structure in the firm and because coordination with other disciplines such as installations is often not necessary.

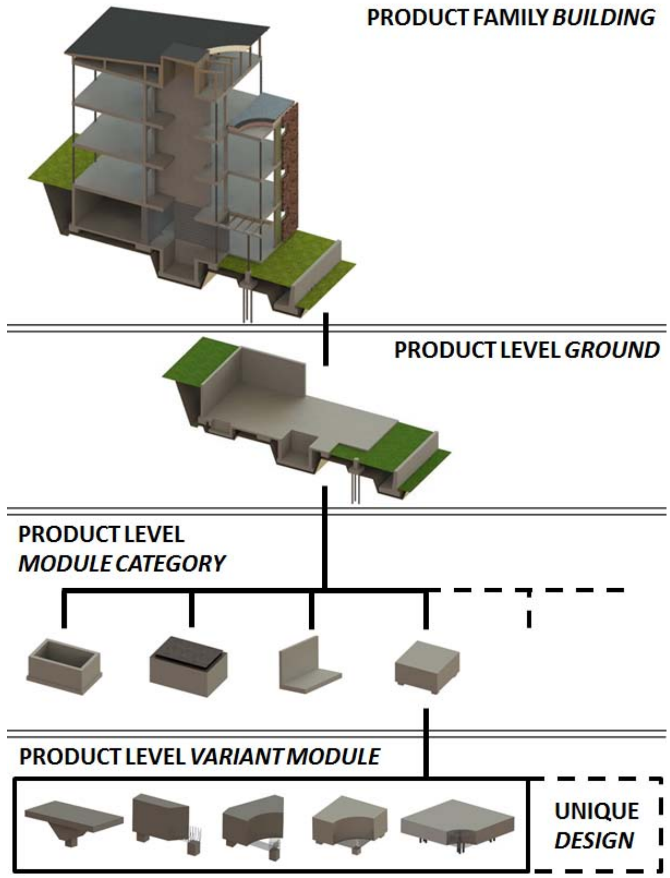

Figure 1: The product architecture for product family of buildings

The survey also identified candidate module categories e.g. the number of designed elevator pits and pile foundation etc. that were present in the collected projects. The answers to the survey also recorded the possible module variants for each module category. For example, if a specific design of a module was detected in more than 10% of the projects investigated, it was listed as a possible variant of that module category. However, other factors apart from the identified module variants could also affect the product architecture. The result of the survey in step 2 was then used in steps 3 and 4.

3. Determining the functional requirements. The functions of the categorized modules in step 2 were identified through their design and by discussion with the experienced engineers. The functions are aggregated according to product level e.g. a pile foundation has the main function of load transfer to the ground at the modular category level, but each module variant can have additional functions. The identified modules from the collected ETO projects are all uniquely designed by different engineers. Many different technical solutions for the same functional requirements were present, with no clear interface between the different modules and the rest of the building as a result. Therefore, the requirements and arrangement of the interfaces of the module need to be untangled and determined in this step.

4. Module categorization. In this stage, the module variant level is defined, see figure 1 which lists the module types for the pile foundations. The number of possible module types corresponds to the usage rate in the projects. When the percentage drops below a certain threshold, they are listed as “unique design” even though they share the same functional requirements at the module category level. The main driver for the company to develop a module variant is having a fast ROI (here ROI is defined as the time to repay the development cost with earnings from the productivity increase). Three types of modules are defined: a standard module present in all designs, a variant module that can be configured to fit the project and a design module that needs to be uniquely designed for each specific project. The design module has the same set of functional requirements and standardized interface together with the other type of modules in the same module category.

5. Development of a configurator. From the unique design modules that have been produced, in this case determined from drawings of collected projects, the common denominators in the product design can be identified. These common denominators are collected from the module types identified in step 4. Accordingly, simplifications in the programming of module configurators can be achieved through inheritance of common attributes and geometries. The next step is to define the output e.g. drawings, specifications, NC files etc. and define how they should be formatted and presented. When the output is defined, the required inputs need to be specified for the configurator to be able to produce the module. The inputs can come from different sources such as building regulations and codes, design rules from company standards as well as knowledge from domain experts on the specific design. Through a continuous dialogue between the development team and the domain experts, solutions, attributes and constraints of the product can be defined. The design of the configurator structure consists of mappings between the inputs and the output of the module. Calculations are then made using the specific product solutions, defined by the inputs. These calculations need to be explained so that users can understand and derive information from them. Simplifications in the calculations can be made to simplify the programming phase and to reduce risks or inconsistencies. Parameters can also be tabulated, for example a variable load can be given in load steps to make the programming more efficient. Also, an increasingly modular product family will facilitate and speed up the development of specific configurators. SolidWorks, and the plug-in configurator TactonWorks, (Jensen et al., 2012), is used in the development of the different configurators in the firm. The configurators are then placed on an intranet server, allowing the use of the configurator to be independent of location and meaning it can be managed remotely.

CONCLUSION

The proposed method for developing configurable product platforms for use in an ETO context, here denoted as products in product platforms, has several advantages compared to existing methods. First, the development can be carried out incrementally, selecting the modules with the quickest ROI time to start the process. Second, the decomposition and analysis of previous construction projects, as illustrated in the case study, shows the potential of utilizing data from the company business management system and knowledge from the organization. This data also made it possible to quantify the possible volumes of different module categories. The division of the product architecture into standard, variant and design modules makes it possible to reuse standard and variant modules to a greater extent and slowly ensure that the technical solutions use a greater number of parts of products produced by the construction industry. One factor that needs to be kept in mind is that, since we only examine what has already been done, data that are collected from previous projects do not necessarily reflect what will be planned in the future. Hence, just copying existing solutions from previous projects can lead to the development of inefficient module designs. However, this is, most likely, a minor problem since modularization of the product architecture will eventually lead to an end product with greater flexibility. Also, the potential for continuous improvements and incentives to adapt the design for build-ability increases as solutions, methods and processes become standardized.

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