USE OF MODULARIZATION IN DESIGN AS A STRATEGY TO REDUCE COMPONENT VARIETY IN ONE-OFF PROJECTS

Ahlam Mohamad [1], Gernot Hickethier [2], Volkmar Hovestadt[3], and Fritz Gehbauer[4]

ABSTRACT

Standardization of work as an essential principle of lean management aims to improve the production process in construction. This paper describes a design strategy which aims to reduce the variety of building components, where this variety affects productivity negatively. The design strategy is based on modularization and standardization. We first review the roots of modularization and standardization, and distinguish the two concepts from each other. Then, we describe the design strategy, which is based on structuring of a building model and defining "modules". The modeling strategy is implemented in two interrelated steps: (1) modularization, and (2) standardization. (1) The process of modularization defines 'chunks' in the building's model and the interfaces between them. (2) The process of standardization aligns the structure of the modules to reduce the variety of components. Creation of these standardized modules during design improves application of standardized work and pre-fabrication. We present the described design strategy in two case studies: The first case study presents an example of implementing the design methodology, and the second case study describes the results of the design methodology in reducing the variety of the components. We conclude that modularization improves the potential for standardization in one-off projects, but it should be applied (1) early in design and (2) in an integrated team to identify customer value trade-offs. Also, a combined application modular design and modular assembly seems promising and remains for future research.

KEYWORDS

Product variety, Modular design, Modular construction, Standardization, One-off projects.

[1] Ph.D. Candidate, Institute for Technology and Management in Construction, Karlsruhe Institute of Technology (KIT), Am Fasanengarten Geb. 50.31, 76128 Karlsruhe, Germany, Phone +49-721 608-44124, ahlam.mohamad@kit.edu

[2] Research Fellow and Ph.D. Candidate, Institute for Technology and Management in Construction, Karlsruhe Institute of Technology (KIT), Am Fasanengarten Geb. 50.31, 76128 Karlsruhe, Germany, Phone +49-721 608-44124, gernot.hickethier@kit.edu

[3] Dr. Engineer, digitales bauen GmbH, Augartenstraße 1, 76137 Karlsruhe, Germany, Phone +49-721 5684 787-4, volkmar.hovestadt@digitales-bauen.de.

[4] Professor, Institute for Technology and Management in Construction, Karlsruhe Institute of Technology (KIT), Am Fasanengarten Geb. 50.31, 76128 Karlsruhe, Germany, Phone +49-721608-42646, fritz.gehbauer@kit.edu

INTRODUCTION

Construction projects can be characterized by three main peculiarities: site production, temporary production organization, and one–of-a kind product (Vrijhoef and Koskela 2005). The focus of this paper is on the third peculiarity "one–of-a kind product". In comparison with other industries, construction projects are mostly one-off projects, where the repetitiveness of work is low, and construction projects can be seen as design-to-order production systems (Winch 2003).

Modular approaches to design and construction have gained popularity within the Architecture-Engineering-Construction (AEC) industry. Modular construction is associated with cost and time savings through prefabrication and off-site work. Modular design is mostly associated with the use of product platforms, which enable mass customization across several projects. However, pre-existing kits sets of building parts which are then kitted into individual buildings constrain design and may not always fulfil customer desire.

Thus, there seems to be a lack of methodology for modular design one-off projects, which do not draw from pre-existing product platforms.

The goal of this paper is to describe a methodology for modular design of one-off projects. This design methodology comprises the concepts of modularization and standardization. First, we present a literature review about the roots of modularization and standardization. Second, we describe the research question and the research approach. Third, we present the observed design methodology. Fourth, we introduce two case studies. The first case study presents an application of the design methodology. The second case study compares the complexity of the Mechanical - Electrical - Plumbing (MEP) systems design before and after application of the design methodology. Fifth, we present conclusions.

LITERATURE REVIEW

BUILDING COMPLEXITY AND ELEMENT VARIETY

Construction projects are frequently characterized as unique projects. This property adds complexity to the design and construction processes. Baccarini (1996) defines project complexity in two terms: differentiation of project elements, and interdependency between project elements. Differentiation refers to the number of different elements, e.g. tasks, specialists, or components, while interdependency looks at the relationships between the elements (Baccarini 1996). Weber (2005) describes five sources of complexity, and one of these is variational complexity: it refers to the number of different component or system variants. Hobday (1998) states that component or system variety causes uncertainty in design and construction. Tommelein (2006) shows that the variety of components adds complexity to the construction process, because it can create variations in the work flow, which may affect productivity negatively.

ROOTS OF MODULARIZATION AND STANDARDIZATION

Although the term modularization is often used in literature, there is no consensus on the definition of this concept and the proper use of it (Gershenson et al. 2004). Modularization deals with the configuration of a product from modules, which can be seen as chunks of the product. Standardization means using identical components or

sub-systems within one product or across products (Fixson 2007). The degree of modularity in a product's architecture depends on several issues, such as, product change, product variety, and component standardization (Ulrich and Eppinger 2004). Next, we present the concepts of modularization and standardization in some early references to research the origins of these concepts. Table 1 shows detailed information.

Alexander (1971) introduced the idea of diagrams or patterns as a key concept for creating the form of the building. Although Alexander did not use the term modularity, this concept is obvious in his ideas about design. Alexander defines the design problem by a set of requirements and interactions between them. He addresses the decomposition process of requirements into subsets as a challenge during design. The task is to divide the requirements into subsets which are connected by a few links as possible as and leaving as many of the links as possible within the subsets. This establishes a hierarchy of subsets of requirements, and each subset can be solved independently of other subsets. Alexander emphasized that conflicts between requirements must be solved as early as possible in design.

In the field of software design, Maynard (1972) addresses that the first idea of modular design in IT was to improve the throughput of a programming department by writing programs as small manageable segments that can be scheduled and developed independently. Designers define modules by splitting program specifications into chunks; this process depends on the logical functions required by the program. Each module shall perform a single logical function or a number of small related logical functions. The goal is that each module can be developed and tested independently. Maynard (1972) defines standard modules as follows "A standard module performs function which is known to be required in future programs or which has a high possibility of that".

According to Baldwin and Clark (2000) "Modularity is a design structure, in which parameters and tasks are interdependent within the modules and independent across them". The process of modularization includes dividing the design parameters into design rules and modules' parameters. Baldwin and Clark (2000) address two issues for the concept of modularity: (1) interdependence within and independence across modules, and (2) abstraction, information hiding, and interfaces. The design hierarchy indicates which information is hidden or visible at different levels of the hierarchy. Visible information is called design rules and is inputs to all subsequent levels; it affects the modules' design. Change of the design rules affects the design of all levels of the hierarchy, where this information is visible. Therefore it is important to define and set the design rules early in the design process. According to Baldwin and Clark (2000), as it is addressed by Alexander (1971), points of interaction between modules shall be as few as possible.Wiendahl et al. (2005) present a concept of modularization for factory buildings. Modularization is considered a core concept to make either individual production systems or the whole factory flexible, and thus robust against future changes in requirements. The requirements of flexibility of a factory building and their effects on the production system must be determined.

Wiendahl et al. (2005) define five planning fields and three configuration sectors for the design process. Each module must be assigned to one planning field and one configuration sector. The concept allows for a hierarchical structure by defining sub-modules. During the design process, standard elements shall be used to create

modules, and the modules may be reused in the five different planning fields of the factory, thus fostering standardization of modules.

To summarize the presented literature:

- It is important to begin modularization early in the design process. A hierarchical structure of systems is the core concept to start with and to apply modular design.
- Setting interface values between modules early on and hiding of information reduces flexibility during the design process. This may hinder innovation and thus reduce product performance, compared to a product without a modular structure (Ulrich and Eppinger 2004).
- Standardization can be seen as a part of modularization and standardization can be applied to elements inside each module, to the interfaces between the modules, or to modules. Standardization can be applied within one product or across different products.

MODULARIZATION AND STANDARDIZATION IN THE AEC INDUSTRY

Literature shows different uses of the term 'modularization' in the construction industry.

Court (2009) defines modularity in production as an assembly system where modules consist of components that can be combined off-site and then delivered to the construction site. CII (2011) identifies potential improvements, such as lower cost, shorter schedule and better quality, through the use of pre-designed modules across several construction projects. Standardized modules can be combined to produce a customized product. Thus, the design phase becomes a configuration phase, in which designers combine available modules into a customized product (Jensen et al. 2009). Veenstra et al. (2006) introduce a platform-based methodology emphasizing the importance to balance standardization and variation in order to meet customer value. Lennartsson et al. (2008) emphasize the importance to balance customer value and delivery team value when defining product platforms and modules in industrial housing.

The presented approaches apply modular design by using standardized modules across several projects. This paper discusses a design methodology for modular design of one-off projects.

RESEARCH QUESTION

Our research question is: How can we improve the potential for standardization of building components and construction operations during the design phase of one-off projects, which are not to be kitted from pre-existing sets of modules?