IMPROVING BUILDABUILITY WITH PLATFORMS AND CONFIGURATORS

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ABSTRACT

The different stages in construction projects are often separated with little interaction between the different trades. Many researchers proclaim that this separation between design and production limits the buildability of construction design. Thus there is a need for providing knowledge of rules and constraints imposed from production into the design of construction products. A way of integrating production knowledge into design is by implementing platforms in construction products. This study will however investigate if and how configurators could function as carriers of both product and process (production) knowledge within platform thinking.

Previous work developing configurators has mainly focused on the efficiency of the design phase and is usually not linked to production improvements and simplifications. By defining a platform for a certain bridge variant within its market segment, the technical solutions can be designed to be flexible while ensuring good buildability in the construction phase.

The developed configurator is built in SolidWorks and parametrically coupled using Tacton Studio. The first version generates geometrical drawings, whereas validation of the generated drawings from the configurator compared with the previous designed drawings from a single case study shows that parametric modelling configurators can be used for increasing buildability and efficiency at site.

KEYWORDS

Buildability, Customization, Standardization, Integration, Platform, Configurator.

INTRODUCTION

The slow growth of productivity in the construction industry in comparison with the manufacturing industry has been highlighted in many governmental reports and research publications in western countries such as US, UK and Sweden, e.g. (Egan 1998, Teichholz 2001). Studies have also identified a large amount of waste generated in traditional building projects, (Horman and Kenley 2005, Mossman 2009), of which a substantial part can be attributed to errors and mistakes in the traditional on-off engineer-to-order product design process, (Lopez and Love 2012). The waste are often attributed the focus on the isolated project in construction and short term

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interactions between loosely coupled partners in the supply chain, (Dubois and Gadde 2002), leading to poor incentives for development of practices, methods and designs that can be reused between disciplines, partners and projects (Mossman 2009).

Waste reduction, e.g. in the manufacturing industry, is normally dealt with using lean production principals and long-term continuous improvements (Womack and Jones 1996). Accordingly, researchers and practitioners argue that the construction industry can learn from lean production strategies applied in the other industries (Koskela 1992, Ballard and Howell 1998).

It is often debated by researchers and construction management that early stages of projects, i.e. design stages, is important in order to operate and manage projects during construction properly (Gerth 2013). Hence, the early stages of design are where projects become limited regarding buildability. Previous case study where the rules of production were taken into consideration in the realization of documents for production resulted in good results in terms of productivity improvement (Simonsson, 2008). Another way of realizing better connection between design and production is to develop platforms from which a stream of derivative product and processes can be configured (Meyer and Lehnerd 1997). Such a platform and configurator should be developed on the basis of modules to fit customers' needs of the target market segment (Hvam et. al. 2008).

The intention of this study is to implement product and tacit production knowledge into a configurator, so that the design can be controlled in the early stage with the ability to ensure its buildability in the construction stage.

PLATFORM THINKING

Several authors claim a product family design and platforms contains the interaction between customer needs and the making of the product that fulfils these needs. Therefore the design can be separated into four views of the product named product portfolio, product platform, process platform and supply chain platform (Jiao et al. 2007).

The product architecture is described as the arrangement and mapping of functional elements to physical components and the interfaces with other interacting physical components (Ulrich 1995). A modular architecture has a one-to-one mapping between the functional element and the physical component of the product which provides the function with de-coupled interfaces between components (Kim and Suh 1991, Ulrich 1995). An integral architecture on the other hand includes a more complex mapping between functional elements, physical components and interfaces between components and is more often found in one-of-a-kind produced products (Ulrich 1995).

A product family is a group of products with similar properties that can be derived from a common platform. Meyer and Lehnerd (1997) define a product platform 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"*. Harlou (2006) quote VW; *"The platform is an entity that has no impact on the vehicle's outer skin"* meaning that things customer cannot see, do not need to be unique and can thus be made standardized. The reason for developing product platforms is the search for increased variety for customer while retaining as little variety between products as possible, this while sustaining economies of scale (Jiao et al. 2007).

However, platform thinking offers insights not only of what a company is offering to clients, but also production information about how these offerings (products) should be designed, produced and delivered (Sawney 1998). This is called the process platform and was introduced by Meyer and Lehnerd (1997) as a complement to the product platform. The products of the platform are realized in a process featuring two central phases: a development phase and a production phase. By using an archive of standard solutions, a minimal number of problems need to be solved on-site. This aspect, combined with high employee loyalty and experience, ensures that the craftsmen know exactly what they are supposed to do when they enter the construction site (Thuesen and Hvam 2011).

In accordance with a given product family, a process family, consisting of a set of process variants, is concerned with the fulfillment of all product variants in the family. Commonality across the variety of product variants leads to a number of similar operations, processes, and sequences among process variants. Therefore, there exist a common process structure within a product family and variety is embodied in different variants of these common structures (Schierholt 2001 and Simpson et al. 2005). A process platform entails the conceptual structure and overall logical organization of producing a family of products, thus providing a generic umbrella to capture and utilize commonality, within which each new product fulfillment is instantiated and extended so as to anchor production planning to a common process structure (Martinez et al. 2000). Kusiak (2002) expressed it simply by saying that a process model (or platform) is a way to collect and organize data and knowledge about processes. The model includes a set of activities arranged in a specific order with clear identified inputs and outputs.

While most literature about platforms derived from manufacturing, see above, it has now starting to gain some acceptance within construction as well. Gibb (2001) stated that, construction companies taking standardization seriously have to resolve the struggle between uniformity and variation, between maximum standardization and flexibility. This challenge of handling standardization and flexibility is central in any platform strategies. Peculiarities like site production, temporary organizations and one-of products have often stated within lean construction leading to high variety and low productivity in construction projects (Bertelsen 2003). Vrijhoef and Koskela (2005) investigated innovative production methods and found that modularity could resolve all three mentioned peculiarities.

CONFIGURATIONS SYSTEM

Product configuration as described by Hvam et al. (2008) is an effective way of structuring products composed of standard parts, and product configuration is also a method of presenting products to customers. The concept of a configuration system is also known as constraint-based programming, where the solution space is defined and can be illustrated by a set of rules determining how components and modules can be combined into products. To be able to address the different stakeholders and disciplines, the product can be defined in product views showing relevant information for a specific actor. The product views with their related product structures can be defined according to Hvam et al. (2008) as; Customer, Engineering and Production view, where the flow and exchange of information from design to production and between stakeholders is believed to be important in order to improve the construction process. Traditional design is transformed into a configuration process supported by knowledge based engineering (KBE) of the final product, (Sandberg et al. 2008, Erixon 1998). Additionally, products structured in a product model (platform) become a company view of the product range that can be held in common by sales, design and production departments and carriers of knowledge.

RESEARCH DESIGN

The research design consists of four steps, see Figure 1. First step is identifying the right product to develop. As proclaimed by Cooper et al. (1999) "Portfolio management is about making strategic choices-which markets, products, and technologies our business will invest in". It was by study a database (BaTMan) that contains all bridges administrated by STA possible to get an overview of possible variants in terms of technical variations and complexity of uniqueness. The chosen bridge variant (end frame bridge) is common, 13% of all bridges administrated by STA in Sweden. Further, the reinforcement solution is not that complex for this variant making it easy to resolve during design, calculation and construction. The bridge variant is thus a good example to develop a modular configurator for, this when product development require less development costs and can be repaid within a limited payback time.

1. Product portfolio	2. Product platform	3. Process platform	4. Configurator
Investigate and choose product variant to standardize	Decompose the products into modules and interfaces	Apply r ght product on process to components and modules	Transfer product and production processes into the configurator

Figure 1: Research design

Second step of the research is decomposition of the product. A functional decomposition of the product was undertaken by a document study of previous projects technical solutions, this in order to find the link between customer demands and functional requirements for the product. The work also aims to ensure that all requirements are met with the technical solutions chosen. General design rules have been acquired through in-depth interviews with experienced design engineers for bridges. These rules form the basis for the restrictions that have been woven into the configurator. Interviews are, according to Patton (1984) an important method to collect information that is unable to observe physically. Rules could for example be how the span affects the thickness of the bridge beam. These relationships have been described in a 2D drawing and serves as a clear documentation of how the model works.

Third step is finding appropriate production solutions for the decomposed product. By performing a full scale case study with focus on production methods, it was possible to obtain knowledge about how buildability could be increased and be a part of the configurator. Production knowledge was taken into account in the design stage, his to improve buildability of the product. The study was performed on a small slab bridge, located in Kalix in the northern part of Sweden, with a span of 10 meters and a width of 15 meters (Simonsson 2008).

The last step is to develop the configurator so that it can function as carrier to both product and production knowledge. Through studying drawings from the case study, where production knowledge had been woven into the design phase utilizing interviews with construction management, material suppliers, design engineers and client, the aim was to generate equivalent drawings using the developed prototype configurator.

DEVELOPMENT OF CONFIGURATOR PROTOTYPE

PRODUCT PLATFORM - CHOOSING TECHNICAL SOLUTIONS

In this project, the technical solutions were chosen when analysing previously projected solutions since these had been proven well thought out, and it would have required a more comprehensive analysis in order to improve production efficiency if starting from scratch. In Figure 2, a functional decomposition of the product is illustrated and how these functions can be treated as "products in the product" (Erixon 1998).

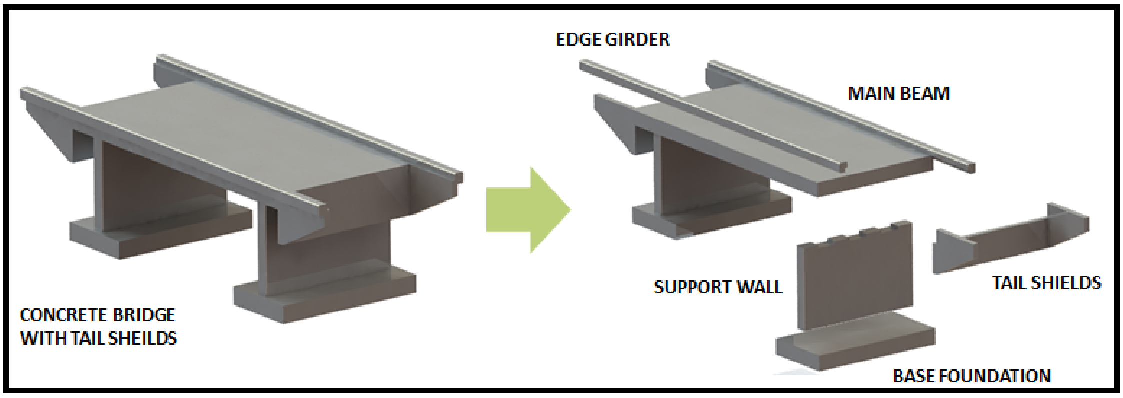

Figure 2: Decomposition of a concrete bridge into modules

When structuring the products in modules with defined functional requirements it is possible to reuse modules between different bridge variants and product families (Jiao et al. 2007). The identified modules have one-to-one interaction between the functional element and the physical component of the product which, according to Ulrich (1995) provides the function with de-coupled interfaces between components. The two most difficult interfaces are between foundation/wall and wall/beam.

PROCESS PLATFORM - EVALUATING PROCESS SOLUTIONS

There are three major production processes when constructing a bridge; formwork, reinforcement and concrete. These are involved in all product modules and the process is always the same, see Figure 2. Hence, identifying process similarities between product modules is one of taking advantage of platform strategies (Kusiak 2002).

Figure 3: Production flow of product module

Innovative production methods, e.g. prefabrication and Self-Compacting Concrete (SCC) are tested during the full scale case study, see Figure 4. Two different types of prefabricated reinforcement were tested, reinforcement cages for the base foundation and rebar carpets for the longitudinal reinforcement of the main beam of the superstructure. Both methods (prefabrication and SCC) revealed good results, concerning both health & safety and time, during construction. Because this was only a single case study, it was not possible to test new production methods for all identified production processes.

Figure 4: (a) Reinforcement cage, (b) Rebar carpet and (c) SCC

DEVELOPMENT OF THE CONFIGURATOR

After both the technical details had been selected and the general rules for how different parameters affect each other, the selected bridge where modeled. When constructing this model, it is important to know which parameters that can be altered and which that are to be locked. By restricting the freedom of the design space using the parametric rules and locks, programming can be simplified. SolidWorks a CAD software often used within the manufacturing industry was selected due to its ability to manage parametric attributes. The model consists of modules, described in Figure 1, that are assembled in the bridge configurator by the use of the parametric attributes. The projection of the 3D model creates a 2D shop drawing that reflects any changes done to the 3D model. When creating this drawing it is important to remember that the drawing is not static and it must be allowed dimensional changes. When the model has been created, various parameters such as height and span attributes where developed in the "add-in" configurator Tacton Studio. For example, the attribute named span where linked to the 3D model length, see Figure 5, where the attribute has been linked.

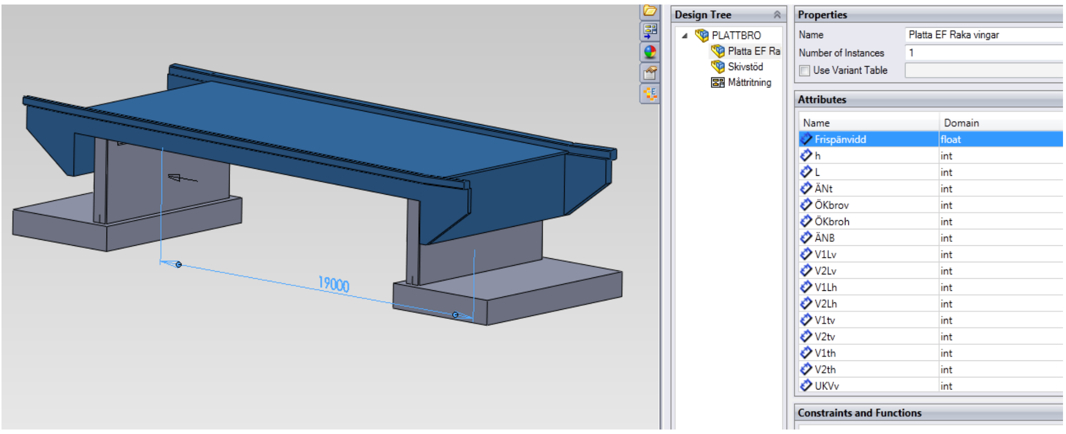

Figure 5: Mapping of attributes to the 3D model

When all selectable parameters are coupled to respective dimensions in the 3D model, the constraints and relationships is described. This is done by using "rules and constraints", as an example the thickness of the bridge main beam is 0.05 times the span. The model with its limitations then needs to be provided with a user interface for the ability to change the parameters for specific projects. How these parameters are to be defined needs to be carefully selected to make the configurator easy to manage and update. Input selection can be done either directly in the CAD program, but can also be published as a user defined web-based interface to the configurator. The choice of interface relates to how and by whom the configurator should be used.

DISCUSSION AND CONCLUSIONS

By dividing the product into functional elements, a modular product structure is created which enables reuse of functional components, e.g. edge beams and the supports that can be reused for other bridge variants. The product structure renders a parallel development, where product and process knowledge can be spread to several product variants. The configurator is thus a knowledge carrier for the platform and its modules.

Validation of the configurator is done by examining the ability to automatically generate similar drawings as in the single case study (Simonsson, 2008). Both the case study and the generated drawings can be seen in Figure 6. The same data as in the case study has been used in the configurator to be able to create the same presumptions for production methods e.g. to be able to use rebar carpets in the superstructure. As seen in Figure 6, the geometrical limitations and constraints have been constructed to enable e.g. edge girder to connect to the main beam while still enabling the use of rebar carpets. This geometrical relation is built into the configurator, regulating rules and constraints for construction. Thus, it is possible to create new buildable bridge designs using the configurator. This is only one of many constraints that have been woven into the configurator.

Based on these results, it is seen that constraints that needs to be taken care of during the design phase have been woven into the configurator, e.g. now the design engineer do not need to have specific tacit knowledge about production to the same extent as before. A centralization of knowledge has occurred where the ability to update the model based on the transfer of knowledge from the unique project has been created. The study also shows that it is possible to combine products with production aspects in a configurator to create a model with both good flexibility and buildability of the product.

Future work will focus on the completion of the configurator and connect it to the FEM program that can generate all the documentation required for the realization of the bridge, but also studying how production documents can be visualized to ease the production at site. After the configurator has been secured, it will be used in a real project where the continued improvement can be measured.

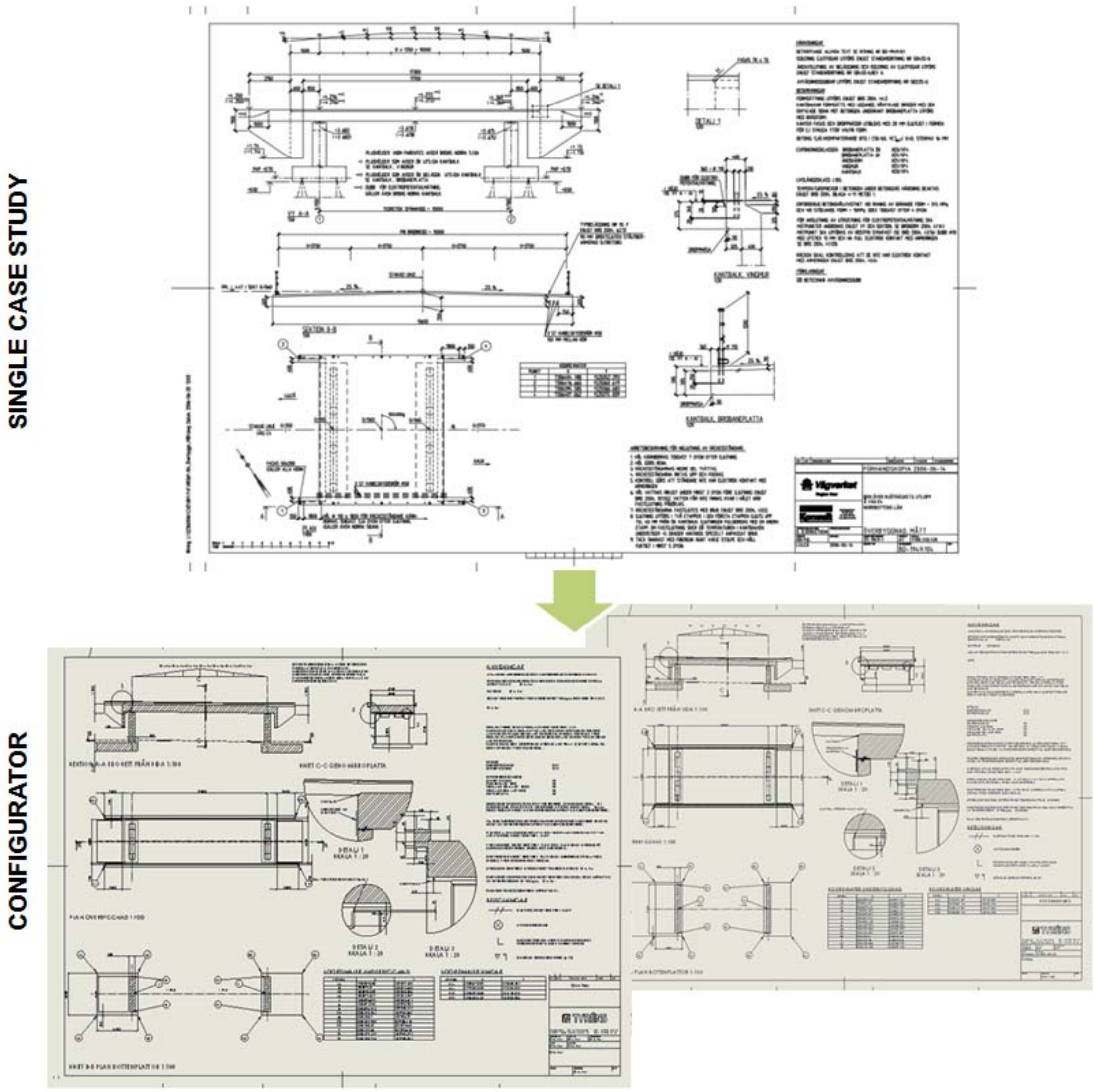

Figure 6: Comparison of generated drawings with earlier studies

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