Integrating Design and Production: A Component-Oriented Framework for Industrialized Housing

Weizhuo Lu, Jarkko Erikshammar and Thomas Olofsson
Department of Civil, Environmental and Natural Resources Engineering, Luleå University of Technology, Sweden
weizhuo.lu@ltu.se

Abstract. This research proposes a component-oriented framework integrating design and production, which enables customer and designer together to customize housing design and avoid ad-hoc design in order to industrialize and standardize housing production. The component-oriented framework facilitates the reuse of components, quickly configures and assesses of alternative housing designs. The developed visualization-simulation modelling provides a consistent and transparent communication platform for customers, designers and builders, where components flow intelligently according to specific sequences, resource requirements, order numbers and durations. A case study of industrialized doors production is used to illustrate proposed component-oriented framework.

1 Introduction

Construction companies in Sweden have been moving work from site to industrialization, especially in the housing industry (Olofsson, Jensen, & Rönneblad, 2010). Most single-family detached houses in Sweden are prefabricated by industrialized timber frame housing companies (approximately 74% from 1990 to 2002) (Bergström & Stehn, 2005). Industrialized housing holds a share of the Swedish housing construction market of approximately 15% (Höök, 2008). The industrialized housing builders perform design and production processes in factories, using industrial machinery. The industrialized factory production of housing components improve productivity, quality and continuous learning (Lessing, Stehn, & Ekholm, 2005).

Clients, architects, structural engineers, contractors, sub-contractors, suppliers and facility operators, often have conflicting interests (Luiten, Tolman, & Fischer, 1998). For industrialized housing, the effective coordination within the design, planning and installation processes is crucial to achieve the benefits of the industrialization (Koskela, 2003). From the clients' view, pure customized housing design, may lead to ad-hoc design solution (Jensen, 2010) which may result in the utilization of industrial machinery impossible and rework for the negotiation of price and delivery time (Hvam, Mortensen, & Riis, 2008); on the other hand, from the pure engineers' view, standardized housing to marketplace result in the low satisfaction of customer and too much speculative housing (Roy, Brown, & Gaze, 2003).

The integration of design and production for industrialized housing construction provides a possible way aligning the interests of design and production. Lean philosophy is also proposed as appropriate way integrating design and construction processes (Jørgensen & Emmitt, 2009). However, the integrating of design and production developed in the manufacturing industry may not be effective when applied to construction projects for the difference from project to project (Faniran, Love, Treloar, & Anumba, 2001). A Swedish industrialized building company was investigated the benefit from an integration of design and production, flexible design when using an industrialised production (customer viewpoint) and the limitations imposed by the preferred standardised components (Stehn & Bergström,

2002). Therefore, industrialized housing builders need to balance the trade-off between lean and agile process to manage and coordinate different view (Lu, Olofsson, & Stehn, 2011).

2 Design and Production Integration

Malmgren et al. (Malmgren, Jensen, & Olofsson, 2010) defined four product views relevant for industrialized building systems: customer, engineering, production and site assembly view. These views shows the interests from the different stakeholders' perspective: The customer view contains the clients functional requirements and is created by the architect or sales department; the engineering view is transformed from the customer view and detailed into building components to be manufactured; the production view contains the necessary information needed to pre-manufacture the building components; the assembly view contains information on how to assemble the pre-manufactured building parts. Figure 1 shows the flow of information and constraints between the different views. Usually, the information flows to downstream, pushing to the following stakeholder. The fact of throwing over the wall makes rework, ad-hoc solutions and conflicts between stakeholders in industrialized housing building system.
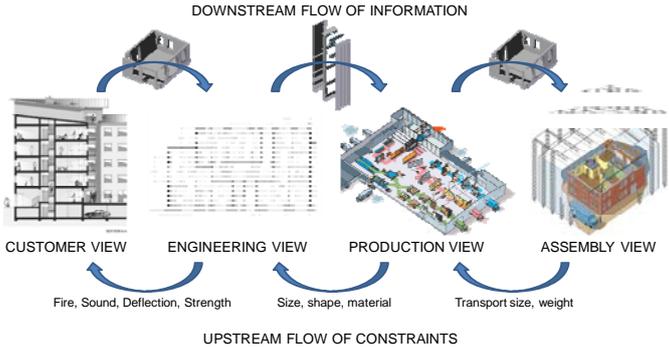

Figure 1: Information Flow between the Different Views (Olofsson et al., 2010)

To coordinate the industrialised housing building system, an effective coordination between customer, designer and builder is necessary. Figure 2 presents a conceptual framework of design and construction integration, in which the design decisions act as the primary input to construction process and the performances of construction process act as the feedback of design decisions. That is, information transfers between design and production considering the clients requirements and production restrictions.
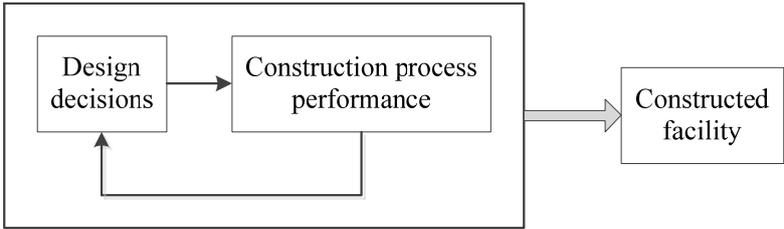

Figure 2: Conceptual Framework of Integration (Faniran et al., 2001)

3   Construction Simulation

Discrete-event-simulation (DES) has been used as a tool for analyzing construction processes since the development of CYCLic Operations Network (CYCLONE) (Halpin & Riggs, 1992). Through computer simulation, the planner can experiment with and quickly evaluate process alternatives in an iterative manner. It provides a tool in terms of which the process can be designed and redesigned until it has achieved maximum production and minimum cycle time with allocated resources. The prerequisite of making useful analysis is to verify and validate the simulation model. Verification is the process of ensuring that a simulation model matches the modellers' understanding of the system, while validation is the process of ensuring that it matches the real or imaginary system (Martinez, 2010). Shi (Shi, 2002) discussed black-box and white-box based methods to verify and validate simulation models. Nevertheless, such verification and validation methods used in most of previous construction simulation techniques are not transparent to all stakeholders. Visualization provides valuable insight into the DES model and facilitates both simulation model verification and validation (Kamat & Martinez, 2001). Hence, simulation-visualization model built with Simio (Pegden & Sturrock, 2009) is developed in this research.

4   Component-Oriented Framework

Component-based software engineering (CBSE) emerged in Software Engineering (SE) as an evolution of the object-oriented approach. The component described by (Szyperski, 1998) as "A software component is a unit of composition with contractually specified interfaces and explicit context dependencies only. A software component can be deployed independently and is subject to composition by third parties." The primary role of component-oriented approach (George & William, 2001; Hasselbring, 2002) is to address the development of systems as an assembly of components; reusability (Components can be reused in multiple application); customization and flexibility (In CBSE, the developers can customize the systems by assembling components according to the specific requirements); maintainability (Components can be updated according to the changing requirements).

Component-oriented approach is very different from the traditional approach in which development of new software systems can only be implemented from scratch. This can be shown in Figure 3, where components can be checked out from a component repository, and assembled into a target software system(Cai, Lyu, Wong, & Ko, 2000).
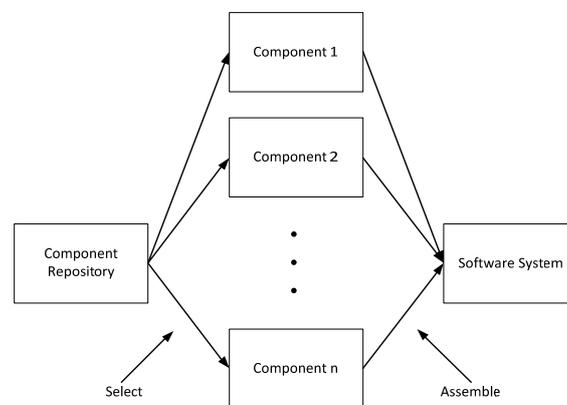

Figure 3: Component-based Software Development (Cai et al., 2000)

In fact, the lean-agile based designs and productions of industrialized housing share the same motivations with component-oriented approach. The industrialized housing needs quickly on-site assembly of prefabricated modules or components produced on factory. Modules and corresponding components are standardized and repetitive (reusable) to utilize industrialized machines, while customization and flexibility to customer requirements are also considered by selecting from different modules and components.

Developing software and designing industrialized housing, both of them, need to manage the balance of standardization and flexibility; to improve the reusability of components to enhance the quality of housing designing or software programming; to assembly the product according to the specific requirements. More importance, quickly configuration and assembly of components avoid the high cost of design (development) from scratch, one-of-a-kind design and production solutions. Nevertheless, industrialized housing involves not only design, but also the production process to realize the detailed design plans. Hence, the effective communication is important to coordinate and synchronize design and production. Considering aforementioned factors, a component-oriented framework integrating design and production for industrialized housing is developed to utilize component-based approach and to coordinate design and production, as shown in Figure 4.
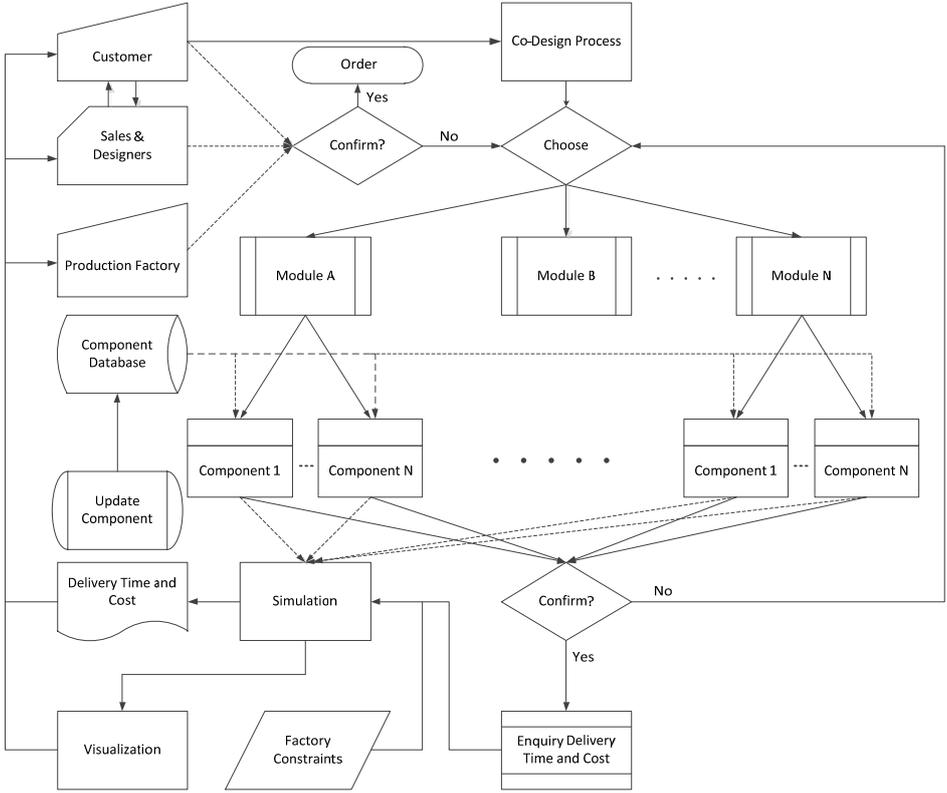

Figure 4: Component-oriented Framework

Within present framework, the sales are able to design industrialized housing and to instruct the customers to choose and decide different modules and components. Sales and customers, therefore, are co-designers of industrialized housing. A customized house can only be developed if the customer is involved in the housing specification process. Sales and customers together decide the dimensions, materials, colour etc. of every selected component. After confirming the modules and components, the enquiry of delivery time and cost, which

includes the information transfer between design and production are simulated by encapsulating specifications in each component. The component is represented by sets of attributes and defined values, such as list of operations, resource required, duration, sequences and order number. The developed simulation model intelligently responses and simulates the production of components according to above specifications of components and factory constraints. Simultaneously, the visualization model provides a transparent communication platform to customers, sales and builders. If conflicts are observed in the visualization platform or customers disagree with the delivery time and cost, this cycle process perform again until all stakeholders are satisfied and agreed with the customized housing design. And then, the order is released. Accordingly, such framework ensures a consistent and effective information communication between design and production. The performance of design is simulated and visualized to involved stakeholders, and the evaluations of the design act as the information feedback to achieve better design solutions.

5 Case Study

The case study was conducted in a Swedish timber component manufacturing company. The company produces doors for industrialized housing construction industry. The doors are adapted to the individual customers' requirements with respect to materials, colour, size (dimensions) etc. As shown in Figure 5, the sales and customers select components, such as frame long side, top side, middle side, arc long side, bottom side and middle side from the components library. For instance, the sales and customers together choose different frame long components from FramLong Library (from FrameLong A to FrameLong F). After the confirmation of door components and door modules (from Door A to Door F), the attributes of each component are specified, such as the sequence, order number and quantity, parameter (to reflect the changing of duration for the different size of component) and resource, as shown in Figure 6. The simulation model collects the order arrival time and respectively order number to differ and visualize different orders, as shown in Figure 7.
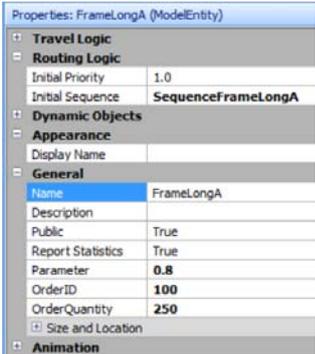

Figure 5: Components of Door Production   Figure 6: Attributes of Components

Figure 7: Order Arrival Time and ID

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In Figure 8, for each component, the sequence of its operation lists and corresponding duration is specified and could be revised if the component is revised and updated. As shown in Figure 9, the customer' order has corresponding number and the components of the same order assign the same order number. The components assigning the same order number are assembled at the assembly workstation according to the corresponding operation instructions.

Figure 8: Sequence of Components

Figure 9: Visualization-Simulation Model of Door Production

6 Conclusions

A component-oriented integrating design and production for industrialized housing is developed in the research. The component-oriented framework which utilizes the component approach provides an effective communication platform for customers, sales and builders. The design decisions acts as primary input to production process, the evaluations by component-oriented framework provide feedback and assessment to selected design decisions. The dynamics and interactive integration model synchronizes information transfer between design and production.

The research responses to the research agenda that "development of an analytical framework for measuring the impact of decisions and undertaking what-if analyses with a view to forecasting accurately project delivery time and cost (Faniran et al., 2001)." This research also contributes the validity of simulation components by visualization to verify the developed simulation component. In a simulation context it is also crucial to ensure that the issue of model credibility and validity is addressed even if the components are thought valid (Oses, Pidd, & Brooks, 2004).

There are some aspects that warrant further study. First, incorporate building information modelling (BIM) in the design performance evaluating and information transfer process. Second, investigate the effect of utilization lean-agile paradigms (Lu et al., 2011; Naylor, Naim, & Berry, 1999) on proposed component integration framework.

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