STANDARDIZING THE PRE-DESIGN-PHASE FOR IMPROVED EFFICIENCY IN OFF-SITE HOUSING PROJECTS

Martin Haller[1] and Lars Stehn[2]

Department of Civil, Mining and Environmental Engineering, Division of Structural Engineering – Timber Structures, Luleå University of Technology, Sweden

Long erection times on-site and project-specific design work, performed by consultants, generally accounts for a large part of correction and building costs in construction projects. In a typical Swedish housing project, the pre- and design phase accounts for about 10-12 % of the total costs. Due to a lack of standardized conceptualization procedures, much of the design work is reiterated in each project, and thus avoidable costs are incurred. In order to minimize these problems an open building system, called MFB, which exploits standardized technical solutions, design and construction processes for off-site prefabricated housing is under development. The MFB system developer will provide a process manual that describes, in detail, standardized design, construction, and erection processes. The open building system relies on close cooperation with local, often small to medium-sized, enterprises that can efficiently undertake “local” building projects. Here, we present and analyse a standard procedure for the pre-design-phase to incorporate in a MFB-process manual. The pre-design-phase of a MFB-building project was recorded and analysed in terms of efficiency. A detailed process map is presented, showing that 122 process steps were logged from the first contact with the client until the generation of the tender. By standardizing the pre-design-phase, the number of essential activities could be reduced by 47%. An improvement in time efficiency of the pre-design-phase with co-instantaneous generation of effective cost estimates should lead to lower building costs in general. Furthermore, by tightly standardizing and controlling the process, it should be possible to repeat projects (or many aspects of projects), without repeating much of the pre-design-phase, even if the actors change.

Keywords: pre-design-phase, process management, project management, project mapping, standardization.

INTRODUCTION

The creation of a new building is organized and realized as a project. Many aspects of the project proceedings are strictly regulated by various building laws, directions and codes, but provided that these regulations are met many other aspects can be extensively varied. Hence, there is great scope for both variation and duplication of design (and pre-design) effort between projects. The study presented here considers the design phase of a recent building project implemented by a certain open building system process. More specifically, we investigate the number of activities involved in the pre-design-phase and the potential to improve efficiency, by comparing the

[1] martin.haller@ltu.se
[2] lars.stehn@ltu.se

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actually conducted number of activities with the essential number of activities in the process.

We then present the development of a pre-design-phase model based on business process mining and lean thinking, which is used to explore possibilities for improving both the efficiency and effectiveness of the procedures. The presented model serves as a base for a process model that can be incorporated in an open building process manual.

BACKGROUND

Masonite's Flexible Building-system (MFB) is an off-site (industrial) I-beam based timber building system. Its main intended application is in the construction of apartment buildings and it is an open building system, or product platform, that is innovative in two respects: it is based on specified technical and detailed interface solutions and incorporates tight control of the building process through certification of the actors.

In the following paragraph a brief introduction in open building is given in order to get an idea what is meant with it in this paper.

The open building concept is based on modular principles (Vrijhoef *et al.* 2002) with the purpose of providing variety (with increased adaptability and flexibility of the building to enable future changes in utilization requirements to be met) through interface standardization with careful consideration of tolerances (Milberg and Tommelein 2004). The rationale is to divide the building into fixed and changeable elements. The building design is standardized and organized into hierarchic ordered levels, i.e. the designer makes decisions starting at higher levels and proceeding successively to lower levels – the output from each level becomes input for the following subordinate level. Thus, the unsystematic process of architectural design becomes systematic in open building Wong (2009). By defining an open building or product platform functional and customer requirements can be more easily translated into traceable technical specifications (Veenstra *et al.* 2006). In a typical turn-key building project the main contractor coordinates the cooperation between the project participants (figure 1a) through sub-contracting contractual agreements. A key element of the open building MFB-system concept (figure 1b) is to organize the cooperation between the sub-contractors by allocating certain process activities to certain roles/actors. Companies must be certified for a specified role. The incentives are calculated in a similar manner to partnering or target costing in terms of shared revenues and losses. The ideal workflow and information flow for each role will be incorporated in a MFB-process certified manual. Thus, different participants will be able to work together within different projects and deliver a certain, specified level of execution quality, even if they have never worked together before.

In conventional building projects, each sub-contractor is contracted based on price and tendering (figure 1a). In a MFB-project the project participants have a common agreement (based on MFB-criteria) that: may be valid for one or several projects, follows the technical specifications, and specifies procedures based on target price acceptance (figure 1b, hotspot B). The MFB-system incorporates technical solutions and specifications, which are detailed in a process manual (figure 1b, hotspot A).

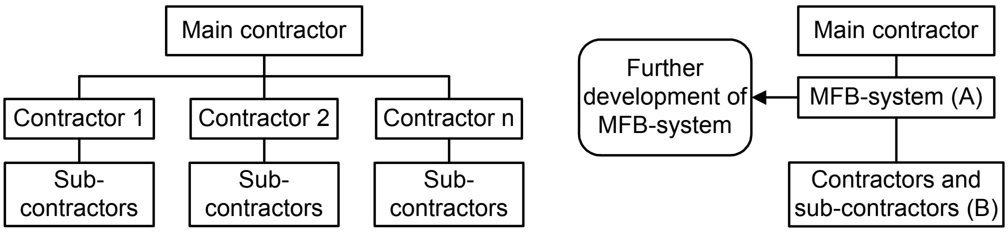


Figure 1: organization structure in a conventional building project (left) and in a MFB-project (right)

LEAN THINKING

The unique characteristics of the construction industry, related to the one-of-a-kindness of projects, the production setup, the construction site and the temporary organization (Vrijhoef and Koskela 2005), are naturally also evident in off-site housing. However, it has been argued that housing construction offers the closest analogy to lean production (e.g., Winch 2003). Therefore, Lean Thinking principles are used as guidelines in this study. Five key Lean Thinking principles can be expressed as follows; (1) precisely specify value in terms of a specific product, (2) identify the value stream for each product, (3) make value flow without interruptions, (4) let the customers pull value from the producers, and (5) pursue perfection. All five principles should, ideally, be combined to help producers identify ways to transform their production systems so that value can be maximized and waste minimized (Womack and Jones 2003). However, the Lean Thinking objective is not to create a perfect process at once. Instead, the aim is to progress towards perfection by stepwise improvement of a stable process.

For analysing and creating proposals for a stable pre-design phase a combination of principles 3 and 5 is used.

- Flow here implies control of the design stream so that value-adding activities can be better managed, based on the assumption that working continuously is both more efficient and accurate than working with interruptions (Björnfot 2006). In the design process, a continuous work flow is interrupted by back loops. If a process contains back loops, or non value-adding iterations, certain activities have to be repeated several times before reaching the objective. Some of this work is naturally creative design, but some is pure flow interruption and waste. To increase the process efficiency, the number of iterations in a design process has to be reduced.
- Perfection here refers to stable and transparent processes and operations, allowing actors to make continuous improvements by experience feedback. The perfection principle is applied, in practice, by striving to produce exactly what is ordered at the right time while eliminating waste (Björnfot 2006).

Efficiency/Effectiveness

Given the pressures on the building sector, it is essential to address effectiveness and efficiency issues rigorously. In the context of the system discussed here, there are potential cost savings and efficiency increases associated with off-site construction, but the direct costs of fabrication facilities must also be considered (Gibb 1999). Indeed, for companies that make large investments in production facilities, processes and product development, optimizing the effectiveness and management of costs to adjust for fluctuations in the trade cycle may be even more critical than for building companies in general.

"… The executive is, first of all, expected to get the right things done. And this is simply saying that he is expected to be effective (Drucker, 2007, p.1) …For manual work, we need only efficiency; that is, the ability to do things right rather than the ability to get the right things done (Drucker, 2007, p.2)."

In this paper, efficiency refers to the ability to formulate a production process and/or generate drawings from a design process in a manner that incorporates continuous attempts to reduce costs and waste. The high level in this dimension represents a Lean strategy.

Effectiveness refers to the ability to adapt the design drawings to the needs of the customer and to respond rapidly to customized variants.

Effectiveness can be conveniently regarded as the ratio between the resulting value of an effort and the consumption of resources involved. Hence, there are two possible ways to increase it: by either increasing the value or reducing the consumption of resources by striving for a continuous work flow and perfection, thereby reducing waste. This study focuses on the latter strategy, examining ways to increase the efficiency of the activities within the pre-design-phase of the MFB-process and thus increasing effectiveness.

BUSINESS PROCESS MINING

The aim of business process mining is to improve the performance and efficiency of business processes in general, and to automatically generate models of business processes by extracting information from event logs in particular (van der Aalst *et al.* 2006).

An event log is a record of process activities, which typically contains process-relevant information such as activity identifiers and execution times (Gaaloul 2004).

In business process mining three different perspectives can be distinguished: (1) the process perspective, (2) the organizational perspective, and (3) the case perspective (van der Aalst *et al.* 2006). This study focuses on process flow control, thus any model developed to describe and explore the examined process should incorporate information about the ordering of the activities and their interactions (dependences and iterations). The organizational data will be integrated in the abovementioned MFB-manual, but not analysed in particular. A problem in process mining is that the designed process model does not necessarily describe the work procedures correctly. It is difficult to detect discrepancies between the actual and modelled process (Rubin *et al.* 2007). As the collected data originate from a single project, just one of many possible paths can be described by business process mining.

DEVELOPMENT OF THE PROCESS MODEL

The development of the MFB-system is still ongoing. Hence, the case project (an annex for a retirement home in Nordmaling, northern Sweden, with two storeys, each of about 550 m2) was set up and conducted as a traditional building project. To develop an appropriate process model, information about the project participants, their roles, activities and interactions needs to be recorded and mapped.

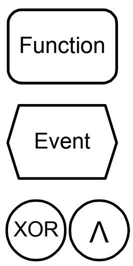
The mapping here was mainly based on an event log following the pre-design phase of the case building project, compiled between November 2008 and the end of December

2009 by the project leader. In order to ensure uniformity of the collected data the data entries followed a directive. The logged attributes were: (1) the date when each of the activities finished, (2) the performers of each activity, (3) a brief description of each activity, (4) the result or output of the activity, (5) the inputs, and (6) the way information was transformed, and (7) a description of any problems encountered. The event log was examined at regular time intervals with the building project leader in order to detect input data errors as soon as possible.

In order to develop a process model an event log has to be searched for causal dependencies. During such searches, two complicating factors must be considered (van der Aalst *et al.* 2006). First, lack of completeness; a log of large-scale, complex processes will not describe all possible routes, i.e. all possible ways of execution. In fact, the log will detail just one possible way, because the input originates from a single project, and hence describes just one route. Secondly, noise; due to technical or human errors some of the logged data may be incorrect. To address these problems, the project leader, the architect and the construction consultant (project participants who were involved in most of the activities) were regularly interviewed. The causal dependences, together with data about the chronology of activities provide information about the arrangement of the events in the process. If there is dependency among them they have to be arranged sequentially. If there is no dependency they can be arranged in parallel. Iteration loops can then be identified by considering both the output of events, e.g. if several versions of a document have been produced, and the descriptions of the activities, e.g. if several sequences include the same order of activities.

The data were tested for contradictions between the input-output links and the order of the activities in terms of time. Missing information about types of splits and joins was collected via interviews. After analysing the data the model was depicted by Event-driven process chain (EPC) diagrams, and the project participants were regularly interviewed to ensure the correctness of the model.

EPC symbols provide a graphical language to model business processes (van der Aalst 1999). An EPC-diagram consists of the following elements.



A function corresponds to a process activity
The situation before or after a function is carried out is described by an event. Events can trigger functions and functions can be triggered by events.
Logical connectors either split or join elements within a process. There are AND, OR and XOR connectors, where XOR stands for exclusive or.

DESCRIPTION OF THE PROCESS MODEL

The pre-design-phase of the case project consists of processes that either can be arranged in a distinct order (the main processes 1 to 6 in figure 2) or that are independent of time (processes i and ii)..

Since the technical system solutions and the know-how to utilize them are crucial for the MFB business concept, information about adjustment feedbacks, due to difficulties encountered during the tendering, was collected in process (i) (figures 1b and 2). This process was triggered when a shortcoming of the MFB-system was detected. The project participants concerned collectively worked out a solution. This process was performed throughout the pre-design-phase.

The second process that cannot be allocated to a specific time is the formation of the project team (ii), since although it was carried out mainly at the beginning of the project, the team was modified whenever a new participant joined the project as it proceeded.

The main processes 1 to 5 were performed in the order shown, with main process 6 occurring in parallel. The six main processes are: (1) the customer acquisition, (2) compilation of the client specifications, (3) compilation of the building programme and the building documents, (4) development of the technical details, (5) compilation of the tender offers and tender submission, and (6) compilation of the project organization (Figure 2).

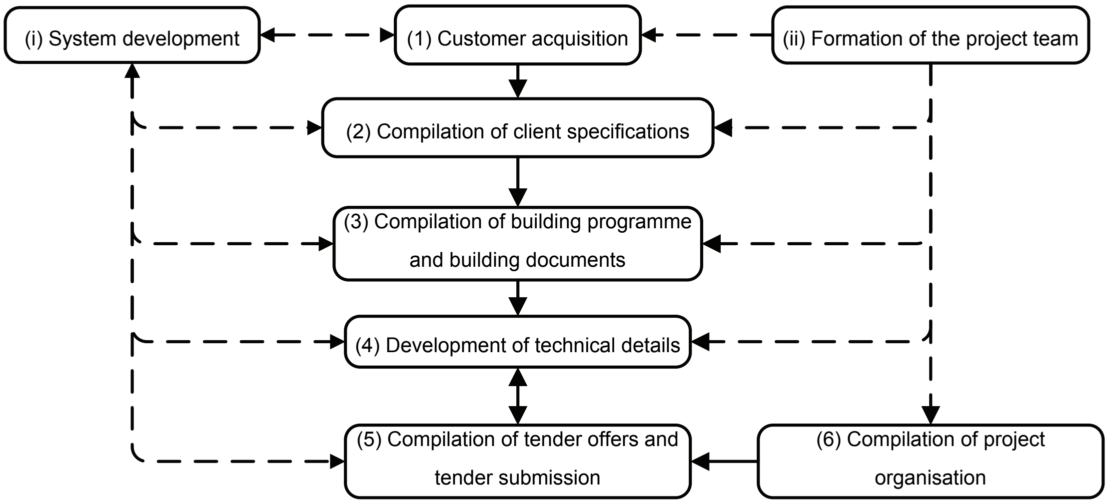


Figure 2: Conceptual flow-chart of a MFB-building project

The arrows between the main processes show the direction of the work flow. The two-way arrow (loop) between the fourth and fifth main processes is present because if the offers were not satisfactory some technical details had to be revised. The two-way arrows between the main processes and process (i) are present for the same reason.

The customer acquisition process was the crucial contact-making process with the client. The aim was to inspire the client's interest and confidence in the MFB-system. The difference in this respect between MFB and traditional construction projects is the total offering of the MFB-system according to figure 1b.

The client's expectations of the building have to be clarified in main process two. For this purpose, the architect sent a check list to the client. This check list contains important and specific peculiarities and critical aspects of the MFB-system. In essence, in this pilot MFB-system the check list was incomplete and contained common but general critical questions. Based on the check list the client compiled the specification list.

The building programme and the building documents were compiled in main process 3. First, the architect drafted a suggestion for the building programme based on the client's specifications. Then the building programme was discussed in terms of feasibility between the architect, Masonite, and the wall manufacturer. When the building programme was eventually completed the architect clarified the specifications for the client and other project participants during a meeting in order to ensure the correctness of all specifications. The outputs from the second and third processes, i.e. the client specifications, the building programme, and the building documents, serve as input for most of the actions included in the forth main process – technical detail development.

Many details have to be agreed, e.g. the standard cross-sections, the ventilation system, the acoustic evaluation, façade and window alignment, and the expected energy consumption. The degree of dependence between these technical details varied strongly. While some details could be worked out almost independently from each other, others had to be adjusted carefully, because they strongly affected other aspects, for instance when a change of technical details affected the appearance of the building. Such changes included changes to details that influenced the building's acoustic properties, energy consumption and window design. When all technical details had been worked out the project participants considered the compatibility of the systems. The outcome of this step, i.e. the technical details, was needed in the fifth main process.

In main process 5 the tender offers were worked out and the tender was compiled and submitted. When the technical details were clear the project participants worked out their offers. Based on their preliminary offers, the project participants, their sub-contractors and suppliers discussed the technical details and occasionally adjusted them, focusing on reducing the offered cost per square meter. When the offers of the project participants were accepted the architect started to make drawings for the tender and all necessary documents, e.g. the implementation programme and the fire prevention document. Finally, the tender offer was compiled and submitted.

The aim of the sixth main process was to develop the project schedule and a commonly agreed allocation of responsibility for the completion of the offers. The project participants worked out suggestions for the project setup, the partnering, target costing and other relevant aspects, resulting in a letter of intent. After a few adjustments, the client accepted this and the results were an input for step number five.

ANALYSIS OF THE LOGGED PROJECT

The analysis in this paper considers mainly processes 4 and 5 (figure 2) because they include most activities, and hence have the greatest potential for efficiency improvements.

In the pre-design phase of the case project, 122 activities were logged in total (Table 1 and figure 2). In an efficiency analysis not all of these logged activities need to be considered. More specifically, 16 of them are irrelevant since they are either decisions, i.e. not activities in terms of time-consuming work steps, or activities that were and will be conducted by the client company, or activities that will not be carried out in future projects. Furthermore, 18 activities can be linked directly to the system development process (i) (Table 1). The number of such activities depends mainly on the status of the technical development of the MFB-detail-solutions. Similar considerations apply to activities in process (ii) (Table 1). Having identified activities that could be ignored for these reasons, 84 of the 122 activities, included in the six main processes, were considered in the efficiency analysis presented here.

Using the definition of effectiveness, the ratio ef between the number of logged activities a and the minimum number of activities amin was calculated. The minimum number of activities is the number of activities required to realize the project without iteration.

Table 1: Number of activities in the pre-design-phase

	min no. of activities amin[]	no. of activities a[]	ef=a/amin []
Customer Acquisition (1)	1	1	1.00
Client Specifications (2)	2	3	1.50
Building Program and Documents (3)	5	7	1.40
Technical Details (4)	16	34	2.13
Tender Offer and Submission (5)	16	29	1.81
Organization (6)	5	10	2.00
Development (i)	-	18	-
Admission Procedure (ii)	-	4	-
Client	-	16	-
Σ Main Processes	45	84	1.87

The overall ratio ef for the main processes is 1.87, indicating that there is substantial potential for improving efficiency in the pre-design-phase. The number of activities could be theoretically lowered by 46.4%. The highest value of ef (2.13) is for main process 4. Most of the iterations are a result of the mutual dependences between variables of the standard cross-sections, including (inter alia) the wall thickness, the acoustic properties, the alignment of the windows, façade design, and the energy consumption of the building. The sequential design of the case project in this process section (figure 3) led to eight different iterations in total.

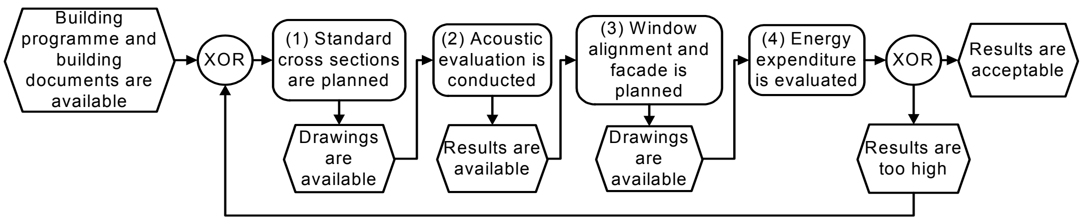


Figure 3: EPC-diagram of activities with high mutual dependence in the fourth main process

The number of iterations could probably be lowered by consistently applying the open building approach, i.e. decisions referred to events should be ordered to several levels, whereas the events in the higher levels determine the design of the subordinated events. As an example, once the wall thickness respectively the wall type is chosen, the acoustic and static demands, a defined maximal allowable energy consumption as well as the type of the window would determine the maximal window-share of the wall which in turn influences the façade design. However, the dependences mentioned above between the events were not the only reasons for iteration. The event log shows that some of these iterations were caused by excessive costs. The technical details were worked out before the related costs were calculated, leading to the mentioned adjustments of the details.

Further reasons for iterations were changes in the client-specifications during the final events of the fifth main process. How much extra work should be invested in main process 2 in order to reduce the risk of extra work due to insufficient interpretation of client demands warrants further investigation. In addition, the iterations in main process 6, the process with the second highest ef-value (2.00), are mainly based on client demands. In practice the project organization had to be compiled several times because the client did not accept the presented solutions.

Some of the main processes include events with subsequent XOR-splits representing a decision, e.g. checking the financial status of the client. When a defined case is terminated, for instance because the client will not be able to afford the building project, the project ends at this point. In order to minimize the risk of failure during an advanced project-phase such terminating events have to be scheduled as early as possible.

It should be noted that the building permission procedure is not yet included in the pre-design-phase.

CONCLUSIONS AND FUTURE WORK

The results of this study indicate that there is substantial potential for improving both efficiency and effectiveness during the pre-design-phase of MFB-building-projects. Problem areas that need to be investigated in more detail are: (1) the mutual dependence of events, (2) the sequential separation of main process 4, i.e. the development of technical details, and main process 5, i.e. compilation of tender offers and tender submission, (3) effects on process efficiency of insufficient client specifications and changes of client specifications during late arranged events, (4) risk analysis and the associated arrangement of potentially terminating events..

Furthermore the results confirm the importance of the availability of standardized technical solutions as well as defined inputs respectively outputs of the particular activities in building projects, as suggested in the open building approach. Thereby the co-operation between project participants gets simplified which in turn contributes to an improvement of the flow.

In order to create a flexible process a tool that the project participants can use to measure the effects of their improvement approaches has to be developed. Rother and Shook (2004) suggest a measuring tool based on the assumption that effectiveness and the process efficiency increase when the resource consumption is reduced while the value is held constant. The cited authors compare value-creating time of a process with the lead time in order to obtain a measure of the efficiency. Since the lead time of building projects strongly depends on the projects' extension, the rationale is to compare the theoretical work time of the process, ignoring the iterations, with the actual work time. In this way each project could be judged regardless of its extension. By recording the time also the quality could also be considered, e.g. by adding time-converted material costs, caused by reparation, to the repairing time.

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