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Analysis of Product Development Connected to Production for Industrialized Housebuilding

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Abstract. Industrialized housebuilding (IHB) is a sector within the construction trade where product platforms have been introduced from the mechanical industry to manage the product architecture and allow mass customization. The aim of this study is to analyze product development projects connected to the product platform and the production. For IHB, the backbone is a technical platform where components are designed and combined. Clients are satisfied, avoiding compromising the technical platform and the product architecture of the different variants. However, the adaptation to production is decisive and production has increased automation, with less flexibility in relation to the products. Still, product development has focused on the engineering view and the development of building components which fit in the predefined or well-established production facility while at the same time satisfy customer demands, i.e., maintaining the balance between distinctiveness and commonality. The study has observed one IHB company and two of their development projects focusing on changes in the product architecture for components across several of their product families. The development has been carried out in a bottom-up fashion. The results indicate difficulties in finding solutions, which fit production. An integrated design of production obstructs product development; the selection of project participants may affect the project results, both in terms of prior experience but also the problem-solving ability; the lack of project documentation is costly since experience is not captured, which could be recycled in future developments.

Keywords. Product development, Industrialized housebuilding, Product Platforms, Production Platforms

Introduction

Industrialized housebuilding (IHB) is a sector within the Swedish construction trade, which has seen rapid development [1]. For IHB, product platforms have become a way to describe and balance the client demands with the demands coming from the production [2-4]. Product platforms supports companies to achieve high levels of product variety, reduced time to market and improved operational efficiency responsiveness [5, 6]. Lessing [7] introduced the concepts of a Technical platform (TP) and a Process platform (PP). The TP includes solutions for modularized building components, with standardized interfaces allowing interchangeability, which align with the starting point for product platforms. However, the technical platform also includes technology in terms of machinery and production tools (as well as ICT tools needed for

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effective production and the handling and flow of related information). In parallel, the process platform entails pieces of collaboration, logistics and information flow. Thus, product architecture is an expression of the technical platform, which is not solely dependent on component design but also production equipment ability and availability. Consequently, product architecture robustness and responsiveness are dependent on production characteristics. While product platforms are a well described mature field of research, production development aspects are rarely applied in product platform literature [8]. Development in IHB has put much focus on automation in production [9]. When the actual operations in production have been verified, improving communication between information systems has gained attention in recent years [10, 11]. However, despite of a platform strategy, customizations are frequently permitted and having superior priority compared to the platform [11, 12]. Important barriers to industrialized building are high capital costs and lack of economies of scale and scope [13]. The challenge lies in the ability to combine a standardized offering from the operational platform with a relatively homogeneous demand from the customer base.

The aim of this paper is to analyze product development projects in IHB connected to the product platform and the production. Empirical data have been gathered from two product development projects at one IHB company across four different phases and includes actual participation in one of the projects and conjoining semi-structured interviews, and document analyses. From the analysis, findings have been extracted ranging from how experience and knowledge is managed to the risks associated to the handling of the product platform in conjunction with the production.

Product development in industrialized housebuilding

For IHB, product development has focused on the engineering view described by [3] and the development of building components which fit in the predefined or well-established production facility while at the same time satisfy customer demands, i.e., maintaining the balance between distinctiveness and commonality. The introduction of product platforms has led to attempts to describe building elements as modules. For example, architectural objects as means to link client requirements and production capability [14]. The IHB platform is the process to transform customer demands to design solutions which fit the production [15]. Jensen et al. [3] made configuration possible using component parametrization. A more recent study on the same theme is presented in [16] where design modules were developed, utilizing design assets in the design process. Similarly, [11] made a product decomposition to identify design assets and build a support for Product Lifecycle Management (PLM) and thereby gain better control over the product architecture and also including a link to production. In another study, Bill-of-materials (BOM) were used to break down the product structure and attempted to improve the communication between the information systems [10]. With a more integrated product architecture, application of platforms becomes more difficult but incremental development from a modify-to-order/configure-to-order can work as a solution [17]. Still, an obstacle for the ability to develop generic solutions for reuse in future projects is that product design and production are introduced in real projects [18]. For development with a closer connection to production, Jonsson and Rudberg [19] introduce a classification matrix dependent on the industrialization level. Linnéusson et al. [20] explored the dynamics between product and production development and the two domains have separate objectives which are not coordinated.

Methodology

To achieve the aim, an approach with four phases was used. An overview of the collected data is presented in table 1.

Table 1. Overview of the data collected from the four phases in the study. (1 = project participants; 2 = project leader; 3 = interviews; x = documents).

	Phase I	Phase II	Phase III	Phase IV
Role				
Product manager	3	1, 3	1, 2	3
Structural engineer 1	3	1, 3		
Technical manager	3		1	3
Platform development engineer	3	1, 2, 3		
Development engineer CAD	3			
Production preparation manager	3			
Production technician 1	3			
Production manager	3			
Project leader building site	3			
Process owner	3			
Business area manager	3			
Production technician 2		1, 3		
Purchase manager		1, 3		
Technician L1		1, 3		
Technician L2		1, 3		
Concept developer			1	
Head architect			1	
Production technician 3			1	
Structural engineer 2			1	
Designer			1	
Documents				
Company descriptions	x			
Process map, new house development	x			
Product component description	x			
Product description L3		x		
Building system certificate		x		
Floor plans L3		x		
Roof hatch drawings L3		x		
Images of components		x	x	
Component solutions Prod. Arch. L3		x		
Load bearing assessment, window block L1			x	
Impact on production, window block L1			x	

- Phase I: Interviews with key roles and scrutiny of internal documents to acquire knowledge about the current state of practice. Eleven interviews were conducted, and data files included company descriptions, process maps, and product component descriptions.
- Phase II: Investigation of a recent product development project from a product architecture perspective. By analyzing the different steps in the development process, the implications when making changes in product architecture could be observed. The analyzed component was a roof hatch initially aimed for product line L3. An additional seven interviews were conducted with project members to evaluate project progression.
- Phase III: To complement Phase II, a second development project was followed, which challenged the product architecture further, i.e., closer to the building system core. The project analyzed development of window blocks to be fitted into the wall elements. The project was followed in real-time.

- Phase IV: Follow-up interviews with the product manager and the technical manager, where the main topic was to make a post-project analysis regarding the development projects.

The gathered data was analyzed to find challenges in product development. The interviews in phases I, II and IV were all semi-structured, using an interview guide with prepared questions. The interviews were recorded and transcribed.

Case company

The main market is residential buildings. Both single-family and multi-family houses are offered with design-build contracts. The products belong to three separate lines.

- L1 – Single-family houses, based on a panel element system. This line allows more choices to the customer, e.g., floor plan configuration. Base models presented in marketing materials work as inspiration to the client.
- L2 – Single family houses, based on a volumetric element system. Customers are only allowed to make floor plan changes that do not violate the boundaries of the volumetric system. Twenty models are offered on the market. A configurator has been developed generating product solutions with different choices (e.g., claddings), which are inside the systems limitations.
- L3 –Multi-family houses, based on volumetric elements. Could be seen as an extension to L2 and L3 is certified up to six floors. Like L2, only floor plan changes that do not violate the rules of the volumetric system are allowed. The different apartment configurations offered to the market are generated from thirteen base modules.

The volumetric element system used for L2 and L3 is configured using panel elements manufactured in the same production line as the ones from L1. The panel elements designated for L2 and L3 is then transferred to another facility where they are assembled into volumetric elements. The produced elements, for all three lines, are transported and assembled at the building site. The production of panel elements is relatively automated and prefabrication level aims at 80 % when delivered to the site. Internal guideline documents describe the product architecture and used technical solutions, including floor plans, choice of materials, building codes and sustainability protocol. The strategy is following the beachhead strategy from [21] where L1 and L2 are interrelated vertically and L2 and L3 are connected horizontally.

Result and analysis

This section reports the outcome from the development projects. Individual presentations are followed by an analysis combing the two projects, also incorporating the post project analysis of phase IV, where problem areas and challenges for product development in product architecture are highlighted.

Phase I: Interviews and initial scrutiny of documents

The interviews and document review resulted in one track focusing on the management and development of mixed product architectures in industrialized housebuilding. Thus, the strategy with three interrelated product lines, founded on the same technical platform, was suitable to investigate further. It was decided to look in to current development projects, which led up to the formulation of phase II and III.

Phase II: Development project Roof hatches

The project took its origin in product line L3. The component is a supplemental module with low impact on the product architecture. The project was carried out bottom-up in the sense that the desired effect was identified, and the progression process was carried out incrementally. The current roof solution is built up by small hatch elements, which together define the roof. The suggested solution would reduce the number of elements, where the original solution typically consists of 70 elements, whereas the new solution consists of twelve elements. The effect desired from the project was to facilitate on-site assembly. Thus, the assembly time, and the risk of moist coming into to the structure could be decreased. In addition, the lower number of hatches would improve the work environment. The smaller hatches were handled manually, while the larger hatches must be supported by a crane in the lifting and assembly, reducing manual labor.

The project was managed by a platform development engineer with 30 years of experience in the company. Initially the goal was to find a solution that fulfilled product specifications in terms of strength, both for the lifting and site assembly. An assigned structural engineer made calculations on load limitations. Already in the early phases of the project, questions were raised about manufacturability and transportation (size limitations). The developed hatches shared dimensions with the old ones, an important characteristic since a size change would rapidly increase the complexity.

The next step was to make samples. A production technician was engaged, and test elements were produced. The assessment demonstrated that the elements fulfilled the specifications and the structural engineer validated that the elements were strong enough, i.e., the geometries were intact after lifting. A current project was selected to evaluate on-site assembly. The production technician monitored the assembly on site, with positive results obtaining faster assembly and improved work environment. Thus, the desired project effects were satisfied. Up until this point in the process the senior development engineer had been responsible for the project progression and while the time frame was rather relaxed, each step could be thoroughly carried out.

However, the question in finding a solution for production in larger batches was lingering and there were also questions regarding profitability since the new elements were tailored to L3. Thus, the company steering group was deciding to make supplemental investigations for L1 and L2. Technicians representing L1 and L2 were assigned. The more open building system, defining L1 (higher customization level), implied that variants of the hatch elements were needed. Customized elements could be produced but it would be challenging to fit into the production. Since the solution was developed for the larger structures defining L3 it also added difficulties when single family houses were investigated. The same problem emerged for L2. Given the additional restrictions in geometry, it was hard to find reuse of the elements and the technician stressed the risk of large impact on the L2 platform.

Thus, even though the project was successful in terms of finding a solution which met technical specifications and satisfying the initially identified effects with faster assembly and improved work environment, there were problems in scaling towards the other product lines and find a production solution that allowed the new elements to be incorporated. Once the project ran into those challenges it was shut down and was not remitted back to revaluation in L3.

Phase III: Development project Window blocks

The project began in L1 and targeted the wall elements and the window block subcomponent, which is produced separated from the wall element production process and the block is then fitted into the wall element. Thus, since the wall elements of L1 also build up the volumetric elements of L2 and L3 this development would have significant impact on one of the base modules in the overall building system. Still, the aim was that the solution would be optional to the client with the intention to keep the rest of the building system intact.

The project was picked up by the head architect in the surveillance of the market where the purpose was to insert multiple consecutive window blocks into the walls. By assembling the blocks back-to-back, the view angles and light admission from the outside would be improved, i.e., the solution removes the disruption that occur between the windows and offers a uniform set of windows. However, to obtain the effects, the supporting stud(s) in the window block had to be slenderer. The window block is designed so that the side studs carry the load coming from the ceiling. Consequently, more narrow studs will reduce the load capability. The project was led by the product concept manager and a project team was formed. The participants represented were concept developer, head architect, product technician, structural engineer, designer, and technical manager. Analogous to the roof hatches, the project aimed to work bottom-up towards a solution that satisfied the specifications.

At the project launch meeting, the production technician raised concerns regarding lifting the blocks in the assembly and that equipment is missing. The structural engineer raised the issue of varying dimensions on the horizontal beam carrying the load from the roof truss. Consecutive window blocks require a beam going across all the window blocks. Still, the starting point had to be in the statics, when the structurally weaker solutions were used. Given the multitude of variants, it was decided to begin in the “worst case” and work your way up. The structural engineer made calculations on a single-floor house with openings in the wall elements allowing different numbers of window blocks and different angles of the roof trusses. The results showed that when using standard material beams, acceptable deflections were only obtained for the two-block width and roof trusses with the largest angles. When using a stronger beam (Glulam), a better result was obtained, and deflections were within the allowed tolerances for all the roof trusses. In the evaluation of adding a third block the deflection was too large for low roof truss angles. Thus, to obtain accepted deflections much additional timber to reinforce the element would be needed which would then risk creating a thermal bridge when insulation is exchanged with extra beams and studs.

The report from the production emphasized risks attached to production efficiency, i.e., increased lead times on some operations and the risk of the window blocks becoming a bottle neck, internal logistics, inventory, and additional items to handle in the ERP system. Other issues concerned work environment and operator safety. Also, the new studs would be too weak to attach the block to the wall element. If using glulam beams the walls could either budge in or out depending on the amount of material. The current solution utilized the stud next to the window block in the wall element to attach slings to lift the elements. With consecutive blocks there would not be any stud strong enough to make the liftings. On the same note, making composite window blocks with multiple windows would implicate problems with lifting equipment missing.

When all the initial analyses were added, the project leader took the decision to shut the project down. The identified problems from the initial investigation would risk propagating into other parts of the building system. Also, since the project demands was not strict and only targeted as an add-on in the offer founded in market trends, it could be argued that the possible solutions would be too cumbersome to implement.

Phase IV: Analysis of phase II, III and post-project interviews

Neither of the two studied development projects led to new solutions being integrated into the technical platform. However, even though the conclusion was the same, there were quite a few differences between the projects. Table 2 gives an overview of key characteristics identified in the analysis, which is followed by a closer look on their impact on product development in the case company.

Table 2. Product development project characteristics.

Characteristic	Roof hatches	Window blocks
Purpose	Assembly, work environment	Market trend, customer demand
Product Line	L3	L1
Building system	Volumetric	Panel
Component	Supplemental module	Base module
Product architecture impact	Low	High
Production impact	Low	High
Approach	Bottom-up	Bottom-up
Time frame	Long	Short

For the roof hatches, the purpose of the project was fulfilled, and the desired effect was obtained. The effect for the window blocks cannot be evaluated since the solution never reached the market. The roof hatch project started in a supplemental module, which initially meant less impact on the ordinary production since the component could be developed in parallel. Thus, the building system defining L3 had little effect, but L3 includes larger buildings compared to L1 and L2 and quickly faced difficulties in the later phases of the project when the solution was examined towards the other two lines. For the window block project, the component with its effect to the core of both the product and the production, meant immediate problems. both in not finding strong enough solutions but also a variety of challenges in production ranging from efficiency to missing equipment and security. The project set-ups in the two projects were quite different. The roof hatches were developed over several years under the long-time experienced development engineer, while the window blocks project was facing a short, planned project sprint with a project team having mixed experience. The reflections coming from the product manager and the technical manager in the post project interviews, mostly focused on the curtailed project with the window blocks. The product manager notes that there are strong wills in the staff both representing the product development and the production and that they need to work together and more unitary. For a project like the window blocks it might have been a misstep to not have pre-project discussions with key roles in production before the launch of the project. Both interviews indicate that the project was launched too quickly with insufficient preparations. Further, the technical manager meant that the representatives from production had less experience of similar projects in recent years.

In addition, a senior project member such as the engineer managing the roof hatch project could have added more critical questions after the initial analyses, lowering the risk of the project been prematurely closed. The technical manger also gave examples where projects could be shortened or stopped early because of prior experience from similar challenges and examples where project results work as input, but due to the lack of structured documentation it is dependent on the staff and their experience. A large chunk of the competitiveness can be found where developed solutions and components are incorporated into the technical platform, which mean that invested engineering hours are returned in future projects where competitors will have to make the analysis from scratch. Other explanations that were raised was that the company is in a process of developing a completely new production facility with a strong focus on automation and that parallel initiatives challenging the suggested production flows in the new unit will face resistance.

Discussion and conclusion

Both development projects demonstrated that adaptation to production is a key to solve. The roof hatches almost made one cycle by being able to develop an acceptable solution but resigned to problems in transferring the solution to L1 and L2. The window block project was almost stopped in the bud where especially obstacles were identified in the production and missing supporting equipment such as lifting devices. Brege et al. [9] state that IHB companies must start the development of their business model in the prefabrication mode, which constituents are the building system and its components together with the level of prefabrication. High level of prefabrication means more developed production, demonstrated in the two development projects. Already Meyer and Lehnerd [21] concluded, strong impact production means the product platform *is* the production process. Thus, product technology and production are equally important. Lessing [7] is including production items such as machinery in his early description of the technical platform and [22] is defining product platforms with the production being decisive as one of four asset categories. Still, in a recent study Boldt et al. [8] reports of the scarce repository of research relating production development to product platforms. When lack of innovation or flexibility is built into the production process, the variety of product versions might be constrained [21]. This is also observed for the IHB case where robustness in the technical platform is positive for the efficiency, but even minor product developments may be cumbersome [23]. Linnéusson et al. [20] stress that even if the product range is streamlined, the link to the objectives in production is weak. For IHB companies operating on build-design contracts this situation is precarious, i.e., operations are production dependent while at the same time, survival is conditioned on satisfied clients, which means that the products must be continuously improved.

Thus, a strategy, which manages demands in the product and its architecture in terms of flexibility in the production is necessary. This challenge was also identified in the post project interviews, whether the product or the production is superior. While the dynamics on the market together with changed building codes and the subsequent changes in product architecture is managed top-down, production development must be made bottom-up since there is less space for changes in the production configuration.

The challenge boils down to the classic dilemma when using platforms, the balance between commonality, represented by the production and distinctiveness, represented by the product and its architecture. Given this situation, it becomes decisive for the company to fully analyze the configuration of their new production facility from a product definitions perspective where automated production equipment may be analogous to integrated solutions in the product architecture.

Robertson & Ulrich [22] included knowledge as an asset domain describing product platforms. The reports from the development projects in this study accentuates the importance of this domain. The way the projects were carried out demonstrated problems in retrieving old experience since a standard protocol to document projects is missing. This situation might exacerbate the problem that less experienced project participants make errors or slow down the progression because of the unawareness of historical projects. With the accumulated experience and competence in the production staff a path forward to utilize this repository is needed.

Stehn et al. [24] stress the importance, to not only, continuously exploit and renew resources and competences, but also to sense, seize and reconfigure cumulative assets over time. A company's capability will continuously be stress-tested since the surrounding environment and its conditions are always changing over time. expressing that business models in IHB has to be prepared for evolvement over time and the progress has to be able to cope with both planned and emergent developments [25].

The operational platform and the market position [26] are not aligned. Offering the entire product range to a large market segment put pressure to the maintenance of the product platform. Analogous to clinging on to unprofitable house models, staying in secondary market segments might be a liability. The inherit interdependence between the product lines, L1-L3 slows down development, especially for minor changes such as in the roof hatch project where economy of scale could only be reached through implementation in all product lines. The technical manager stressed that developments could be incorporated into the technical platform and much of the competitor advantage lies within that fact. However, that statement is important also for unsuccessful development projects. For example, a path forward could be that development projects should be documented in a protocol including a developed approved solution, followed by an analysis of what implications the new solution is putting to the production, preferably in a way allowing future assessments where identified challenges are possible to cluster permitting an overall evaluation of an investment. Thereby developments and investments in product architecture can be justified not based on solely one product line or even on a single component.

This paper has analyzed product development projects connected to the product platform and the production. The results from the two projects underlines a few important points; an integrated design of production obstructs product development; the selection of project participants may affect the project results, both in terms of prior experience but also the problem-solving ability; the lack of project documentation is costly since experience is not captured, which could be recycled in future developments.

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