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# Exploring the Technical Platform in Industrialized Housebuilding for Robust Product Architecture

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**Abstract.** Improved resource efficiency, in industry and throughout the product life cycle, is a challenge and potentially, integrated product and production platforms can act as support. The aim of this study is to explore the current state of the technical platform in two industrialized housebuilding (IHB) companies from a mixed product architecture perspective. The study is part of a collaboration also involving three manufacturing companies and one IT provider. The research is crossing borders by means of interactive research and transdisciplinary engineering, and more than 50 practitioners and 13 researchers with competences in product management, engineering design, computational engineering, software development, production development, testing, quality, sourcing, and project management have been involved. Product platforms have been introduced in IHB to better control mixed product architectures and allow mass customization. Commonly, there is a technical platform for product architecture management, and a process platform for production management. High customization levels have resulted in an increasing number of variants not efficiently utilizing the technical platform. The results show that strong clients have negative influence on the technical platform while offering multiple products may facilitate simpler management of the technical platform but makes it more difficult to make changes and improvements.

**Keywords.** Product and Production Platforms, Industrialized housebuilding, Transdisciplinary Engineering

## Introduction

Industrialized housebuilding (IHB) is a sector within the Swedish construction trade, which has seen rapid development [1]. The sector has traveled from adaptation of general rules during the 1990s, to increasing prefabrication levels and streamlining production up until the early years of the 2010s. In the last ten years, product platforms have become a path forward to describe and balance the demands coming from the clients and the market with the demands coming from the production [2-4]. Thus, market and manufacturing coordination are crucial when applying product platforms [5].

The construction sector has been characterized with an Engineer-to-order (ETO) production strategy [6], which means that the design phase and the management of recurring assets becomes crucial to be successful. While the initial focus for IHB

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development was to increase automation in production [7], lately more work has been done to improve communication between different information systems [8, 9]. Lessing et al. [7] underline, IHB needs to be strategically managed on the systems level and not on the building project level. A move towards industrialized house-building means the shift from strictly project-based production to a more process-oriented production [10].

For IHB companies, the building system construct becomes the core of the product platform and product architecture [11]. Product platforms should support companies to achieve high levels of product variety, reduced time to market and improved operational efficiency responsiveness [12, 13]. Thus, a robust product architecture core can generate multiple product families based on the same building system.

Lessing [14] introduced the concepts of a Technical platform (TP) and a Process platform (PP). The technical platform is intending to cover solutions for building components, IT, and machinery, while the process platform entails pieces of collaboration, logistics and information flow. Experience is gathered from real projects and processed in the development of the platforms, meaning that platform development is integrated with the real projects. Consequently, the robustness and the responsiveness of the product architecture relies on the condition of the technical platform.

However, the housing market is volatile and despite the presence of a platform strategy, customized solutions are prioritized over the platform [15], also outside the boundaries of the technical platform [8]. The aim of this study is to explore the current state of the technical platform in two industrialized housebuilding (IHB) companies from a mixed product architecture perspective. The resulting description offers a starting point for continued robust and responsive development of technical platforms within IHB. Collected empirical data include semi-structured interviews from the two companies, company internal data files and tracking a product development project at one of the companies.

## 1. Mixed product architectures in industrialized housebuilding

Modular product architectures is an enabler, reducing internal variety through standardization, while maintaining external variety towards the market [16]. By combining common components and distinctive components, product variants can be offered to the market. The balance between distinctiveness and commonality is crucial for ETO-companies [2]. For IHB, the product architecture has been scrutinized by modularization attempts for various purposes. In an early attempt, Veenstra et al. [17] demonstrated the opportunity for the housing industry to adopt product platforms and modularity. Wikberg et al. [18] used architectural objects to create a link between customer requirements and systems capability. Jensen et al. [3] demonstrated how configuration was made possible using parametrization of components. Further, Jensen [19] investigated platform architecture and modularity within construction and the results showed that for an ETO-based context and integrated product architecture it is difficult to apply platforms, but by approaching the problem from a modify-to-order/configure-to-order perspective, platform theory can be applied by incremental development. Jansson et al. [20] characterized an IHB platform by a process of transforming customer demands to design solutions that fit the IHB production. To improve digital communication between information systems attempted to breakdown the product structure within IHB using an approach including Bill-of-materials (BOM) [9]. On the same track, Lennartsson et al. [8] 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. However, since product design and production are introduced in real projects, the ability to develop generic solutions to be reused in upcoming projects is hindered. Product design and production are carried out in projects, which is an obstacle for the ability to develop generic solutions to be reused in upcoming projects [21]. Thus, to be successful when employing a platform strategy in IHB you must know the platform scope and boundaries.

## 2. Methodology

### *2.1. Settings*

The study is part of a larger research collaboration bringing together practitioners and researcher to address resource efficiency in industry and throughout the whole product life cycle. Beside the two companies involved in this paper, there are three manufacturing companies and one IT solutions provider involved. These manufacturing companies are all working internationally, while the IHB companies are primarily acting on the Swedish arena. More than 50 practitioners and 13 researchers with competences spanning from product management, engineering design, computational engineering, software development, production development and testing to quality, sourcing, and project management have been involved. The research is characterized by crossing boarders, interactive research and transdisciplinary engineering where practitioners and researchers work together in the knowledge/solution creation process. More information regarding the overall research project can be found if searching for, IDEAL - integrated product and production platforms, on the Jönköping university webpage.

For this particular study, the initial interviews described in the next section were part of a larger study where the current practice was investigated also in the other participating companies. Thus, a common interview guide was developed, and the formulated questions were blended by the practice in the manufacturing companies which helped in the analysis.

### *2.2. Strategy*

To achieve the aim, a two-phase approach has been used. The first phase included semi-structured interviews with key individuals at the two companies. The motivation for this approach was to acquire in-depth knowledge about the current practice in the companies. In total 10 interviews were conducted at Company 1 (C1) and 11 interviews were conducted at Company (C2). The respondents were selected strategically from a product and production development experience perspective. The questions covered current practice, challenges and opportunities in product and production development including integration and boundary objects of the studied companies. The interviews were conducted using online video calls. In average, each interview lasted for 90 minutes. All interviews were recorded and transcribed. An overview of the conducted interviews for both phases is presented in table 1. To support the data collected from the interviews, internal data files from the two companies were scrutinized. For C1, documents describing standard solutions/operations, documents describing the technical platform and product declarations were gathered. For C2, documents describing standard solutions/operations, possible floorplans of product line L3 and technical certification of product line L3.

An initial analysis of the collected data was conducted leading into the second phase of the approach where a product development project regarding roof hatches was followed at C2. Thereby, the management of the technical platform could be scrutinized in a real current development. The motivation to look further into C2 was motivated by their technical platform having three different product lines which is described in the results below. Documentation from the development project were scrutinized and an additional set of seven semi-structured interviews were conducted, specifically focusing on the progression and the process of the development project. Respondents were all involved operationally in the development project, where respondents 7 and 12 were leading the way. Analogous to the first phase, this run of interviews was also conducted as online video calls, with an average run time of 90 minutes. These interviews were also recorded and transcribed.

**Table 1.** Overview of the conducted interviews for the two phases in the study.

| Role | Phase 1: Company 1 | Phase 1: Company 2 | Phase 2: Company 2 |
|---|---|---|---|
| 1. Business area director | | x | |
| 2. Product Manager | | x | x |
| 3. Project manager | x | | |
| 4. Purchase manager | | | x |
| 5. Process owner | | x | |
| 6. Technical Manager | x | x | |
| 7. Development engineer platform | x | x | x |
| 8. Development engineer CAD | x | x | |
| 9. Production manager | x | x | |
| 10. Production preparation technician | x | | |
| 11. Production preparation manager | x | x | |
| 12. Production technician | x | x | x |
| 13. Project leader building site | x | x | |
| 14. Designer | x | x | x |
| 15. Technician L1 | | | x |
| 16. Technician L2 | | | x |

## 3. Result and analysis

This section presents the state of practice for the technical platforms at the two participating companies. The presentations are based on interviews and documents retrieved from the companies. The analysis at C2 is enhanced by also including a development project regarding roof hatches. The subsequent analysis combines the two cases and indicate problem areas in the current way of working from a mixed product architecture perspective.

### *3.1. Company 1 (C1)*

C1 is focusing on functional buildings such as, schools, kindergartens, elderly homes, and offices. The products are all based on a volumetric element technical platform (building system). The overall strategy is to prefabricate up to 90 % of production in a factory. By offering their clients turn-key contracts, the company is covering all disciplines and the entire construction process. To become competitive knowledge client operations, deliveries, competence, and low cost are crucial. Commonly, clients are municipalities and other public actors.

The technical platform is conceptually described in a five-level decomposition of the product. The TP is illustrated from top level 1 (house) down to level 5 (parts). The superior level is described by parts from the adjacent subordinate level. The platform depends on the house models and their decomposition.

The company is missing a protocol to manage the clients and therefore more customizations are allowed, which means the risk of departing from the TP increases. Further, developers are often having large funding and are able to set a narrow frame of demands and also change the demands underway. Consequently, during the product realization process, novel solutions are often developed without any effect analysis for the technical platform, i.e., the number of product variants increase out of control (demonstrated by the vast number of documents residing in the company project archive). Thus, even though the company is fostering a standard product assortment, the value of the predefined models is miniscule.

The backbone of the TP is a Standard operations guideline system that describes the different technical solutions within the building systems. Still, the system is categorized following a construction guild structure, divided into 10-15 technical departments rather than modularity, making development and management of the TP more challenging. According to the technical manager, the TP is not fully defined or described. The company has developed a process to support TP development, including factors such as time, cost, impact on the platform and the production. However, allowing customizations and the illogical structure of the guideline system makes it difficult to align. There are also only a few members of the staff (technical manager and structural manager) that have proper experience to make changes to the TP. Therefore, designers find their own way of working and experience and knowledge get stuck in individuals rather than a common accessible repository.

From a product platform and mixed product architecture perspective, this way of working is a risk. Even though the company is offering solutions from many product lines on the market, it is difficult to be prosperous with additional design work, project specific changes to the TP. From the interviews, symptoms such as successive project development and adaptation, as well as late drawing changes were reported. Consequently, the production needs to be flexible which is difficult to manage since prefabrication and a fixed factory are prerequisites for IHB. This is made possible since the production still includes large portions of manual carpentry. More flexibility in production also means more project specific production preparations, which indicates that the project has not followed the rules of the TP.

### *3.2. Company 2 (C2)*

C2 is primarily operating on the residential market, including both single family houses and also multi-family houses, with up to six floors, with larger developers involved. The products are divided in to three lines. The first line (L1) contains of single-family houses and is based on a panel element building system, which offers more customization options to the client, for example floor plans. The second line (L2) also offers single-family houses but applies a volumetric element system with strict standards and customization possibilities are scarce, which means that floor plans are fixed. In total twenty models are offered on the market. The third line (L3) is offering multi-family houses and applies a volumetric element system and similarly to the second line, floor plans cannot be changed. The residential units are generated from 13 base modules. Notably, the volumetric elements used in L2 and L3 are using the panel elements from L1. Thus, L2 and L3 are offspring of the original L1 product line. Given the product offer from C2, they have clients that are small but also larger developers. Following the restrictions attached to line two and line three, a standard product assortment has been developed and for line two there is a configurator available for the client to design their own product within the boundaries defined by the company. The beachhead strategy (Fig. 1) developed by Meyer and Lehnerd [22] can be related to the strategy with three different product lines where L1 and L2 are interrelated vertically and L2 and L3 are connected horizontally.

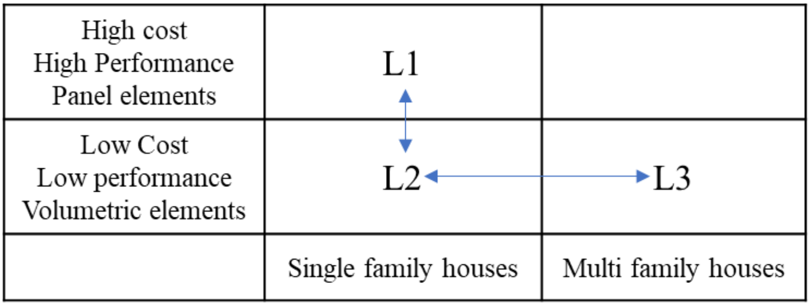


**Figure 1.** Positioning the product lines in C2 according to the beachhead strategy developed by Meyer and Lehnerd [22].

Production is located in two units where the larger unit is producing the panel elements for all three lines and elements intended for L2 and L3 are then distributed by truck to the other units where the volumetric elements are assembled. Both panel elements and volumetric elements are manufactured in production lines with relatively high levels of automation. Prefabrication level should be above 80 per cent when the elements are ready for delivery to the building sites. For all three product lines, the completed elements are transported to the building sites where final assembly and completion are carried out.

C2 has developed company internal guideline documents for their different products that are describing the product architectures and used technical solutions, including floor plans, choice of materials, building codes and sustainability protocol. For product lines' two and three these guidelines are decisive and customizations violating these standards are not allowed. Thus, there is documentation of the TP from a product architecture perspective. However, there are no instructions describing the logic and philosophy when it comes to developing and managing the TP. Also, there is no formal way of working or checklist for development of the TP.

### *3.2.1. Description of the development project at C2*

The starting point for the project was development of larger roof hatches for L3. The aim was to facilitate building site assembly, which would reduce the risk of weather induced moist coming into the structure by cutting the times of assembly. Further, by reducing the number of hatches work environment would be improved with less heavy liftings. Being the multi-family product line with larger final buildings, L3 was suitable for the development. The initial assessment was that the implications of this development was minor for the building system and the TP.

The project was initiated by a senior development engineer with 30 years of expereince in the company. In the starting phase, models of the new hatches were developed. These models were remitted through a structural engineer to verify the strength in the new component, both after assembly but also for the lifting and actual assembly. The new component had the same dimensions as the old solution, which was important since changing the look would quickly have elevated the project in complexity. Test specimens were manufactured in the factory. The test concluded that it was possible to produce the new components and proved that the geometries were intact also after lifting. A suitable ongoing project was then selected to test the assembly on-site where the results indicated reduced time of assembly and better work environment and thereby fulfilling the initial aim of the project. However, if the new component was supposed to be incorporated the TP, the company needed to find a production solution for the factory. The cost evaluation showed that the volumes for L3 alone were not motivating an investment and it was decided to add investigations of L1 and L2 to scale up the number of hatches to be produced.

The higher customization levels attached to the L1 products reinforced the challenge to align the manufacturing of the hatches with existing production. With more customizations the potential for the hatches was reduced, i.e., smaller, and different sizes. Thus, having a wider definition of the TP does not automatically mean simpler development of new components. Also, for the L2 products the new component presented problems connected to the TP. The strict geometries attached to the roof solution of the L2 products did not align with the hatches developed for L3 and making reuse more challenging and reducing the potential.

In conclusion, even though the newly developed component fulfilled the technical demands and therefore becoming a candidate to be included in the TP there were problems to find an acceptable solution for the production where more than one product line was included. To quote one of the responses from the interviews *"unless it is feasible in production we are not going to proceed*".

### *3.3. Analysis of the technical platform from a mixed product architecture perspective*

The descriptions of the TPs for C1 and C2 are rather similar where the building system is the foundation in both companies. C1 solely using volumetric elements while C2 has a path allowing more customizations (L1) with panel elements and two product lines using volumetric elements similar to C1. Both companies also strive towards high prefabrication levels and quick assembly at the building site. However, there are also differences where the directions have different impacts on the TP (Table 2).

**Table 2.** Differences of characteristics influencing the technical platform.

| Characteristic | Company 1 | Company 2 |
|---|---|---|
| Market segment | Functional | Residential |
| Client impact | Strong | Moderate/Low |
| Design work | High | Moderate/Low |
| Automation in production | Low | High |

For C1, operating in a market segment with functional buildings it has proven to be difficult to keep the TP intact when strong clients are allowed to make customizations. Further, low level of automation in production put less restrictions on the product offer and yields more work in design. These characteristics have resulted in a large amount of product variants and making it hard to get a holistic view of the TP. The blurry boundary of the TP makes it easier to be responsive since new variants having unique product architecture can be developed continuously.

For C2, mainly operating in the residential market segment the situation is different. Especially for L2 and L3 customizations are kept on a low level and persistent clients can be steered to the L1 segment. Combined with a rather high level of automation in production the company is having better control over their TP, which also reduce design work and the risk of generating variants and solutions isolated as islands in specific staff individuals. Therefore, the TP exhibits a more robust description. However, the development project demonstrated the difficulty to make product developments where the TP is affected. Even though the project with the roof hatches was rather simple and the desired effect was achieved, the results showed that it was hard to align an expansion of the production to the different product lines and product architectures. Further, the senior engineer initiating the roof hatch project is a key asset in terms of being an experience and knowledge repository.

## 4. Discussion

In both companies the production adaptability is a cornerstone, which is a fundamental part of IHB. For C1 there is a struggle to manage the TP properly. They allow customized solutions to the client and consequently the efficiency in production suffers. These characteristics have been observed in other studies [2, 23]. In a way the TP becomes responsive by offering a wider range of products with different product architectures but then C1 is moving towards the traditional construction industry with the exception that they need to adjust the production while a classic construction project can tailor the production according to the developed product. Thus, the basic idea of IHB, to increase efficiency through prefabrication is either lost or diminished.

For C2 the TP is managed in a more robust manner, where the building system is applied strictly for product lines L2 and L3 and customizations can be directed towards L1. On the other hand, an area to investigate further might be when TP development originates in the L1 product line, which often means more design work and the L2 and L3 products are generally trying to avoid additional design work. The beachhead strategy also calls for gentle development since a weak platform can compromise an entire product line [22]. The roof hatch project demonstrated how much the production influences development of the TP. Even though the hatches had little impact on the TP from a functional perspective, the analysis regarding production made it a challenge to implement, which is also observed by Meyer and Lehnerd [22]. Especially since all three product lines were needed to motivate the investment. Thus, C2 is protecting the TP from unjustified changes and for minor projects with an existing solution, such as the hatch example, there is no problem.

However, there will be future demands where new solutions for an updated version of the TP is needed. Also, a stronger TP increase the risk of moving too far away from the market and the demands of the clients that might lead to an unbalanced focus on buildability instead of client satisfaction [2], which also includes product definitions [24]. The readiness in C2 for those kinds of challenges is not complete, e.g., missing guidelines and instructions to manage the TP and strong dependance on a few senior staff members with most of the collected experience from developing the TP and the different product lines over time. The problem with a few key members of staff was observed also for C1 and with a growing number of variants that probably exacerbated the condition of the TP.

Robertson & Ulrich [25] mentioned knowledge as one of the asset domains describing product platforms already in the 1990s. The results demonstrate that knowledge dissemination is important regardless of which end of the spectra for the TP you belong to, i.e., prioritizing responsiveness or robustness. A recent longitudinal study [26] of the development in the IHB sector reports on the ability to not only continuously exploit and renew resources and competences, but also to sense, seize and reconfigure cumulative assets over time. The study originates in the fact that many studies only report from a snapshot in time while the surrounding environment is always dynamic and therefore a company's capability is always challenged. Thus, the TP management in C1 and the poor or missing documentation in C2 combined with the knowledge lodging in a few staff members in both companies becomes a liability.

As mentioned, the study was part of a larger project. Companies coming from other disciplines were participating and 13 researchers were involved conducting the interviews adding more perspectives which also influenced the post-analysis and results. The strong research environment and rich repository of data is characterized by crossing boarders, interactive research and transdisciplinary engineering where practitioners and researchers work together in the knowledge/solution creation process.

## 5. Conclusions

This paper has explored the current state of the technical platform in two IHB companies from a mixed product architecture perspective. The results show that inability to reduce the client interference and allow customizations lead to an unintended expansion of the product range and also the product architecture by adding new components to the TP without any effect analysis. It makes it simpler to be responsive but risks to destroy the production efficiency which yields more design work which may exacerbate the condition moving the operations towards traditional construction practice. A more robust TP will have positive effect on the production efficiency but in a situation where the platform is the basis for multiple product lines changes and development may turn out to be more cumbersome. Especially if the production is part of the development.

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