A FRAMEWORK SUPPORTING MIXED PRODUCTION STRATEGIES IN PLATFORM DEVELOPMENT: A CASE STUDY IN POST AND BEAM BUILDING SYSTEM

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Industrialised house building (IHB) design incurs complexities as extensive engineering are required due to high customisation. Companies use different production strategies (PS) to develop building components ranging from standardised to customised depending on the requirements. Platform-based product development has received increased attention from IHB companies striving to be competitive in the industry. However, strategies for platform development supporting the design process are not well-defined for companies using a combination of PS in their development. This study proposes a framework using different PS in the development of a product platform to support the design phase of the post and beam IHB system. Empirical data were gathered from a Swedish multistorey house building company. The main contribution of this study is to provide insights into production strategies while designing components. Moreover, the case is used to exemplify how different subcomponents of the building system can be classified into production strategies and facilitate postponement of strategies to achieve platform-based development. The potential application of different support tools and methods in incremental platform development has been presented.

Keywords: design management; industrialised house building; production strategies

INTRODUCTION

The design phase of IHB is challenged to develop products with lower costs and reduced lead time (Jansson *et al.,* 2014). The degree of detailing and information level increases due to unique requirements from the customers, legal challenges, market demands, production constraints etc. (Thajudeen *et al.,* 2022). Here, extensive engineering work is required for certain components as customisation yields a high level of complexity (André and Elgh, 2018). Consequently, the construction industry has been traditionally characterised as being engineer-to-order (ETO) in the engineering dimension (Gosling and Naim, 2009). However, companies use a combination of PS to develop building components ranging from select variants to ETO depending on the customer needs (Thajudeen *et al.,* 2018). Researchers, therefore, highlighted the importance of Customer Order Decoupling Points (CODP) by introducing different PS from pure standardisation (no customer input) to pure

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customisation (customer engaged in design) (Schoenwitz *et al.,* 2017). According to Johnsson (2013), pre-engineering is a potential option for ETO companies, although firms allow the client to affect the product design. In fact, ETO based companies can apply many product standardisation strategies by defining part of the product structure and preparing reuse of existing designs to increase efficiency (Cannas *et al.,* 2019).

LITERATURE REVIEW

For the design of customisable products, product platform and product family are the two key elements (Meyer *et al.,* 2018; Simpson *et al.,* 2014). Platform-based product development has received increasing interest from IHB companies that strive to be competitive in the industry by offering customised solutions and lowering internal costs (Lennartsson *et al.,* 2021). Research on product platforms (Jansson *et al.,* 2014) and product customisation (Hvam *et al.,* 2008; Jensen *et al.,* 2015) indicates that modularisation requires customers to move from ETO strategies to configure-to-order (CTO) strategies, in which the CODP point changes. Here, the level of predefinition must be increased for components and the CODP must postpone to a later stage of the value chain to achieve the benefits of the use of platforms (Bonev *et al.,* 2015). There are plenty of strategies and methodologies for companies to rationalize their product portfolio. Despite various studies on product platforms and PS in the IHB industry (Bonev *et al.,* 2015; Jansson *et al.,* 2014; Johnsson, 2013), some research gaps remain, particularly when it comes to supporting the design process of building components having a mix of production strategies. Moreover, Cannas *et al. (*2019) identified the need of investigating different choices in terms of the combination of decoupling points and strategies. A better understanding of the impact of PS and product architectures on design and production processes is therefore needed to facilitate platform implementation. Therefore, this study proposes a framework using different production strategies in the development of a product platform to support the design phase of the post and beam IHB system.

Product platform strategies have been widely accepted as enablers for customisation to serve a wide variety of products while maintaining business efficiency (Bonev *et al.,* 2015; Jansson *et al.,* 2014; Jensen *et al.,* 2015; Meyer *et al.,* 2018). Robertson and Ulrich (1998) defined product platforms as a collection of four sets of assets, namely components, processes, knowledge, and people/relationships. Platform thinking enhances component decomposition in terms of commonality parts and modularity parts guide a way to adopt the pre-engineering strategy (Jiao *et al.,* 2007). Jansson *et al. (*2014) suggested integrating design support methods for daily work when using platforms in an ETO context. Hvam *et al. (*2008) proposed an approach for the development of configuration systems for predefined platform components. A study performed by Thajudeen *et al. (*2022) demonstrated how to reuse the design assets of building components having ETO characteristics with the support of parametric modelling. The design platform approach (DPA) is used to gain the benefits of platform thinking in a company utilising both the residing engineering assets and as a formalized model that can be supported by IT applications (André and Elgh, 2018). Several studies have been conducted adopting DPA in both manufacturing and IHB industry (Lennartsson *et al.,* 2021; Thajudeen *et al.,* 2022). The different constructs of DP include Process, Solution, Synthesis Resource, Assessment Resource, Geometry Resource, and Project and have been considered as the building stones of a product variant. These resources are linked to a generic product structure (André *et al.,* 2017) and can be used for modelling any components ranging from standard to unique in terms of their degree of predefinition.

CODP refers to the point at which the customer enters the supply chain and to explore the potential for platforms and companies can use different PS based on CODP (Johnsson *et al.,* 2013). The four strategies used by companies according to Hansen (2003) are ETO, modify-to-order (MTO), CTO and select variant (SV). A view of two-dimensional CODP has been introduced by Wikner and Rudberg (2005) in which engineering and production are considered as different flows of activities that can be dissociated independently (Cannas *et al.,* 2019). Moreover, they refined the engineering dimension and dissected the ETO production strategy to extend into three strategies which are design-to-order (DTO), adapt-to-order (ATO) and engineer-to-stock (ATS). These diversifications of the ETO strategy were further tested by Johnsson *et al. (*2013) with a multiple case study in house building. The findings show that the DTO based strategies of the platform are undefined while ETS platforms are fully predefined. A movement away from the ETO strategies followed in traditional construction to a more product-oriented based on a MTO, CTO, or SV strategy represents a shift from a project focus to a greater focus on processes and products (Lundkvist, 2015). Here, the combination of PS presented by Hansen (2003) and Wikner and Rudberg (2005) has been used as a framework for empirical analysis.

Table 1: Analytical framework of production strategies with definitions (adapted from Hansen (2003) and Wikner and Rudberg (2005)

Production strategies	Definitions
ETO	The highest level of customization is categorised by the fact that engineering work needs to be steered for each customer order. The subset of ETO is DTO, ATO, ETS as below
DTO	Entirely new products are designed from scratch.
ATO	When parts of the solution are pre-engineered to some extent and the final product is realized through combining these parts.
ETS	The condition where solutions are pre-engineered.
CTO	Provide automatically configured product variants based on fully defined product parts, modules, and a set of configuration rules.
MTO	Supported by generic product structures and predefined modules and sets of rules that govern the design of product variants.
SV	Product development by use of standard components and processes.

The literature review shows several examples of platform-based development studies from different applications areas. However, they are mostly focusing on specific PS. Moreover, there seems to be no research that deals with the mix of PS strategies supporting the platform development from a complete building system perspective.

METHOD

The research was performed in two stages: Data collection and data analysis with framework development and validation. This study uses the combination of case study research and literature review by following a qualitative approach. A Swedish multi-storey house building supplier using a post and beam system was selected as the case. A case study allows focusing on a particular issue within a real-life context (Yin, 2018). The unit of analysis was subcomponents of a building system with a varying level of predefinition, each following a distinct production strategy. Figure 1 shows the overview of the research process.

A literature review presented in the previous chapter was the starting point of this study. An analytical framework was created by selected PS with their definitions to familiarise the participants from the company. This is used during the interview to compare the PS of different components, supported by parallel analysis of data. The empirical data were gathered from interviews, workshops, reviews of the archival sources and other sources such as informal conversations.

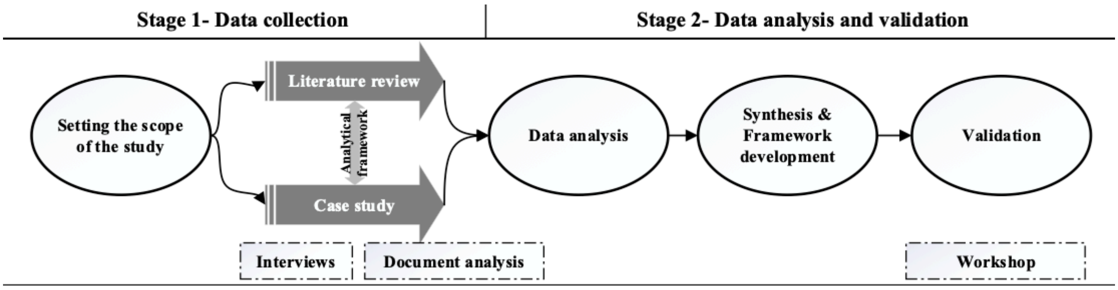

Figure 1: Overview of the research process

Here, method triangulation has been employed to increase the accuracy of data and to test validity through the convergence of evidence from different sources (Yin, 2018). In total, 5 interviews were performed ranging from 1-to 2 hours including the design manager, two structural engineers and two design engineers. The participants were selected based on their experience and knowledge in building systems from various positions in the companies, which enabled a more consistent understanding of the product portfolio. The intention was to gather additional empirical insight into the applicability of different PS and the impact of platform-based product design.

The interview results were analysed by categorising data for individual building components to examine the suitable strategies to adopt while designing. Besides, archival data sources helped to find different strategies adopted by designers in previous projects by analysing the 3D models of buildings, design templates, excel spreadsheets, custom component libraries etc. A framework has been proposed with the support of gathered data. Finally, a workshop was conducted by including key personnel from the case company as part of the evaluation and to investigate the impact of the support method and its ability to realize the desired situation.

Case Study

A Swedish subcontractor of Glulam (Glued laminated wood) based multi-storey housebuilder has been selected as the case company. They offer a multi-storey house building system named Trä 8, a flexible, wood-based and lightweight construction system for both residential and public buildings. The main reason for the selection of the case is due to the degree of predefinition offered by the building components and the uniqueness in all projects offered by the building system. Moreover, they are currently working on the adaptation of a platform-based development to be more competitive in the housing market. The main components of the building system are shown in table 2, including pillar/ post, beams, trusses for stabilisation which are made of glued wood, floor elements and roof elements made of Kerto material and steel connectors. The product view and subcomponent view of the Trä 8 building system is shown in Figure 2.

Framework for Platform Development

A framework is proposed for the case company to support platform development by adopting the benefits of PS in component design. An overview of the framework is shown in Figure 3. This is developed based on a detailed study of individual sub-component of the Trä 8 building system with the support of experienced designers during the empirical data collection and motivation gained from the literature study.

The practical goal of this study is to increase the understanding of suitable production strategies while designing a component with the support of a product platform.

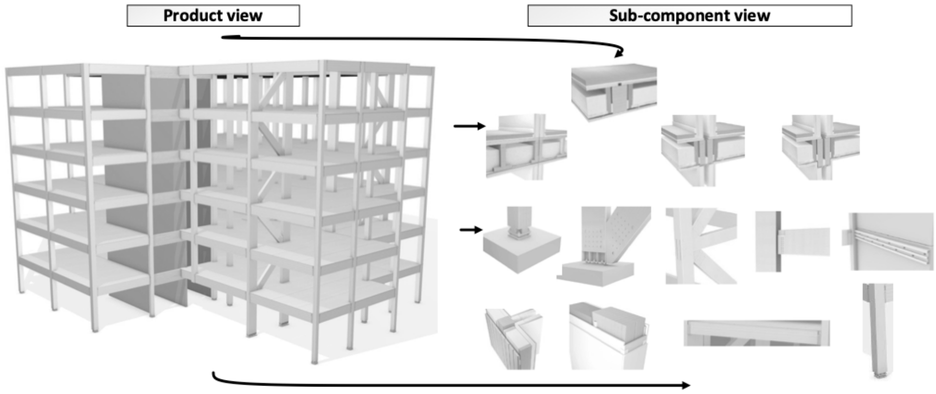

Figure 2: The product view and subcomponent view of the Trä 8 building system

Table 2: Components of building system

Components	Description
Post	They are made by gluing small lamellas and are used to handle the vertical load both compressive and bending forces imposed on the building which is anchored to the concrete foundation.
Beam	The beam primarily functions as the vertical load-carrying member from the floor element of the building. It is connected horizontally to the posts with the help of steel connectors.
Trusses	Trusses are the diagonal structure that is used as stabilizing members to balance the fluctuating load. The truss elements are connected to the column with steel fin plates and dowels to provide stiff connections between the members.
Floor element	They are built with a top slab of laminated veneer lumber (LVL) sheet and beam frame of glulam where cavities are insulated with mineral wool for sound insulation. The elements are light, and stiff, which contributes to good characteristics of failure, vibration, and soundproofing, especially at low frequencies.
Roof element	The roof structure is most conveniently designed with the element of LVL discs having surface insulation with a layer of insulation on top of the element.
Steel connectors	Steel connectors are designed to transfer imposed loads from one structural member to another and then to the foundation. All building components are connected with steel brackets that are designed for a rational assembly.
Stabilizing element	The main stabilization element is the staircase and elevator shaft which is generally made of the concrete structure and the purpose is to stabilize the entire post and beam structure, especially with high span.

As shown in the figure, the development includes the conceptual phase, the system-level phase, and the detailed design phase. The proposed framework can be used as decision support for designers in the design phase. The core part of the framework is the classification of building components based on the PS adopted for the product realisation. The PS developed by Hansen (2003) and the subset of ETO presented by Wikner and Rudberg (2005) has been utilized. Every component follows a PS based on its level of pre-engineering (Johnsson, 2013). The colours represent the level of complexities in designing the building components. For instance, steel connectors have been considered as a critical component of BS having an ETO nature that requires extended engineering work whereas the framing components such as post, beam and trusses can be realised easily based on the load and span width of the building. The subset of ETO has been used due to the characteristics of the components offered by BS. Table 3 shows the detailed classification of components into different PS and existing support used to design together with the support of engineers.

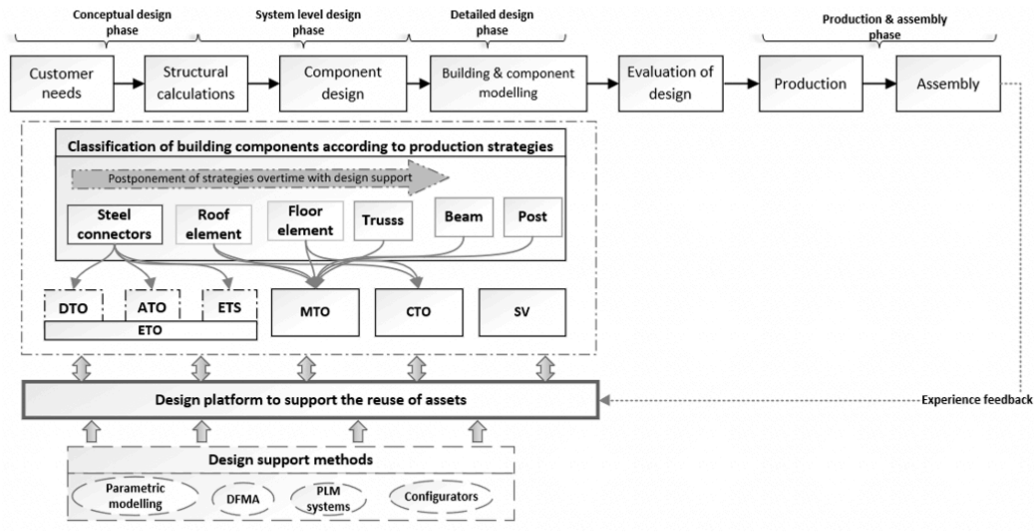

Figure 3: Framework for platform development using mixed production strategies

The key criteria for the classification of components are the knowledge of different assets and experience in designing. For instance, the design of a new component starts generally with DTO and could incrementally move from the subsets of ETO to MTO, or CTO based strategies as shown in the figure. From a design platform perspective, this is occurred due to the reusing of design assets where the solutions created for the first time in DTO can be adapted for the next project, and turn into an ATO strategy (André *et al.,* 2017). To achieve this postponement in design, the designer must first distinguish components that need to change and determine how such changes propagate through different attributes.

In principle, the structural calculation for post, beam and trusses starts from scratch for all projects as requirements are unique. Here, the dimensions of these components depend on the span width and internal and external loads. Structural engineers often reuse the previous solutions such as Mathcad sheets, excel sheets made from the previous project to some extent and adopt them for new projects. Currently, several Mathcad files for brackets, column footing, and floor elements are reusing. For the modelling, custom component libraries, BIM managers and parametric modelling are currently used as support for developing solutions. Here, the assets are predefined, and this way of working can be related to the DPA (André *et al.,* 2017). It can be methods or tools that enable reuse in the early stage of engineering as a support for designers. However, engineers do not have a structured and shared approach to follow.

DPA was chosen as it can be used for the realisation of ranging from standard to unique variants supporting the generic modelling of a product platform using the product structure and design assets of a company (André and Elgh, 2018). It supports sufficient review and assessment of design variants available and guides designers in the process (Lennartsson *et al.,* 2021). Hence, a good alignment can be achieved with components that provide an idea about what kind of asset can be built and used in different projects. Moreover, the approach is intended to expedite the decision-making process that supports the designers with a set of proven design solutions and assets to find an optimal solution.

Table 3: Classification of building components and mapping of production strategies

Building components	Subcomponents	Production Strategies	Structural design support	Modelling support
Post	215X225 mm - 215X 800 mm	MTO	Excel guide, Statcon	BIM manager
Beam	90X360 mm - 215-900 mm	MTO	Excel guide, Statcon	BIM manager
Trusses	215X225 mm - 215X 800 mm	MTO	Excel, Trusscon/ RFEM	BIM manager
Floor element	Variant 1- LVL	CTO and MTO	Mathcad	CCM, Semi-PM
	Variant 2- CLT	CTO and MTO	Statcon/Rfem	CCM, Semi-PM
Roof element	Variant 1	CTO and MTO	Mathcad	CCM, Semi-PM
	Variant 2	MTO	Statcon/Rfem	CCM, Semi-PM
Steel connectors	Column footing	DTO, ATO ETS, CTO	Mathcad	CCM, PM
	Column footing with truss	DTO, ATO	Mathcad, Statcon	Manual modelling
	Bracket	DTO, ATO ETS, MTO	Mathcad	CCM, PM
	Truss connections	DTO	Statcon	Manual modelling
	Stabilizing part	ATO, ETS	Mathcad	PM, BIM manager
	Balcony	DTO	Mathcad, Statcon	Manual modelling

CCL- Custom component library, PM- parametric modelling, CLT-cross laminated timber

If the designers have an overview of components in a platform, the same can be reused across different kinds of projects by adopting a platform approach. According to the structural engineer, "Platform development based on PS could benefit the design process and change the culture of way of working". This helps the company to improve the level of pre-engineering. However, the potential of DPA has not been fully explored. This was the motivation for a structured framework for supporting a platform-based product development by utilising the PS of sub-components.

The framework suggested various support methods and tools that are potential to use to improve the design process. As pointed out by Jansson *et al. (*2014), the support methods are employed to reduce the gap between the standardized components defined in a platform and the project-specific parameters. For example, the results from Thajudeen *et al. (*2022) show that by integrating the parametric modelling approach, it is possible to change the engineering strategy gradually from ETO to CTO strategy to be more efficient in the design process and meet the challenges due to customisation. Reuse of engineering assets of ETO based components can push the boundary towards adoption of the configuration of variants from those components. This initiates the incremental development of platform-based design in a firm (André *et al.,* 2017). A high degree of interdependence between the variants leads to the generation of a high number of variants. The knowledge about the component assets is crucial when moving towards CTO or MTO approach. Finally, the experience feedback from production and assembly creates a complete loop where information is feeding the designer for any variations (Lundkvist, 2015). As part of the evaluation, the proposed framework has been verified in a workshop by including key people from the case company.

DISCUSSION

IHB companies typically place themselves randomly in a PS without having a thorough knowledge of own assets and not conducting a detailed analysis of the subcomponents. Developing project-specific and unique solutions create a perception that the BS follows an ETO based strategy (Schoenwitz *et al.,* 2017). However, in reality, building components can be even classified into various PS and companies can develop strategic decisions based on the component portfolio (Johnsson, 2013). Several components can be classified to be configured or modified depending on the functionality where the power of reuse can be adopted (Cannas *et al.,* 2019). Thus, familiarizing the product portfolio from a production perspective something simple to understand and tangible is important for success.

This is an explorative study performed to analyse the possibilities of classifying subcomponents of BS according to the mix of PS to find what is the rationale for this classification and what picture can be drawn from a product platform perspective. The analysis of BS shows that post and beam type IHB companies typically build houses with components that have a combination of standard, modified, configurable and fully customised building components (Thajudeen *et al.,* 2018). For instance, the framing components can be developed with the MTO approach based on different loads acting on the building. Here, design preparations are not required to a great extent but ensure the components are structurally strong and withstand the loads. However, connectors require a more ETO approach. Thus, the concept of simply reusing the process and product from a previous project cannot be directly applied in the engineering development of ETO based components. The growing degree of complexity inherent in the ETO approach due to fluctuating changes eventually leads to higher design time and cost. For example, the brackets have variants ranging from MTO to ETO where a few could be standardised and the rest require more effort in design (Thajudeen *et al.,* 2022). Here company can allocate more resources and support methods to those components that need more attention.

By applying different engineering support methods ETO-based components can be shifted towards MTO or CTO (Jansson *et al.,* 2014). This is achieved by the pre-definition of different assets gathered from a component and the reuse of those assets in future projects brings a platform-based development (Bonev *et al.,* 2015). Some special components are always started from DTO and then adapt to other types of strategies. This can be considered as part of incremental platform development achieved by reusing knowledge (André and Elgh, 2018). In this context, a DPA would be the suitable platform approach that can take care of component design ranging from standard to ETO nature (André *et al.,* 2017). Moreover, the postponement of production strategies is the key outcome of using this approach. The novelty of this study is an approach to platform development based on a detailed classification of a BS from a holistic perspective.

The results show that one way to adopt platform-based development is by the postponement of existing PS with support methods and tools. Also creates opportunities to streamline the design process, balance resources and focus on tasks that certainly require engineering knowledge and skills. Designers can build a strategy based on this framework and highlights the importance of decomposing a product before making decisions. These benefits support the ideas of BUILD BACK WISER from a construction management perspective, by improve the design phase. The main implication of this study is that understanding the different dimensions of component variants, their interconnections, and possibilities to achieve various designs would help designers select the production strategies that are appropriate for their specific context (Hansen, 2003; Wikner and Rudberg, 2005). The understanding of the platform not only includes components, but also other assets is important for any company to adopt a platform culture. There is a potential, if the assets can be added to a platform and managed regularly, not individually, but also shared with other designers, more to be seen as a design platform asset. This framework would provide a path forward for the case company to improve the design process. Therefore, the industrial contribution includes adding knowledge about the platform development based on PS and best practices to improve the design process of building components. Here, the classification of components is made with the support of designers from the company which improves the reliability of the work. Moreover, the archival data and workshop support the evaluation of results.

CONCLUSIONS

This research has attempted to identify the dimensions of PS in a post and beam IHB system and establish a way forward to achieve a platform-based product development. A framework is proposed that highlights the importance of the DPA for the reuse of assets (André *et al.,* 2017), the choice of PS in the engineering dimension (Hansen, 2003; Wikner and Rudberg, 2005) and how components can be classified with the support of a design platform. The developed framework can be used as a road map for the case company to develop a strategic decision-making tool and adopt this support for designers in developing solutions. The findings reported in this paper are specific knowledge gained from a single case based on their BS (Yin, 2018). However, this case is an explorative study to obtain a preliminary result from the application of the proposed framework. This could be an inspiration for other types of BS and can be assessed to test the practical applicability in a different context. The disposition of PS may change in different contexts based on the component's nature, customisation offered, level of pre-engineering etc. More detailed studies are required to show how this approach can be realized and this can be considered a future study.

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