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Platform use in systems building

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The practice of reusing processes and technical solutions leads to the formation of product platforms in house building. Product platforms originate from industries employing a make-to-order production strategy, e.g. the automotive industry. To test how the product platform concept is useful in engineer-to-order production strategies, a case study at two Swedish house-builders was made. Key factors that affect platform use in systems buildings were sought. The smaller company operates a supplier-led platform focusing on commonalities in process knowledge. There is less definition of the product itself to allow for distinctiveness in the product offer. The larger company has a decentralized business and operates a client-driven platform with fragmented standardization. Focus is put on creating commonality through defining the product and handling distinctiveness through an iterative design procedure. Product families were not in use at the case study companies. The companies transform standardized platform solutions into project uniqueness by using support methods. Four platform support methods emerged from the case studies: design planning, collaborative design, design optimization, and requirements iteration. The balance between commonality and distinctiveness in the platform is important to attend to in each house-building project. The engineer-to-order production strategy hinders the implementation of a fully parameterized platform. The product platform concept is therefore expanded with support methods to handle distinctiveness, i.e. project uniqueness. The product platform assets: components, processes, relationships and knowledge, are present also in platforms used in systems building.

Keywords: Case study, design, industrialized building, product platforms, support methods.

Introduction

The Swedish housing sector has seen a strong development of systems building stemming from the long tradition of industrialized production of single-family houses (Samuelsson, 2001). Prefabrication with systematization of processes and components was the foundation in systems building during the industrialization of housing in the middle of the twentieth century (Finnimore, 1989). Current demands for shorter lead times, customized buildings, and quality of deliveries compel construction firms to systemize work in their own supply chain. The design phase is today a critical part of construction with high demands on timely and exact deliveries produced over the shortest time period possible.

Construction design in general suffers from inefficiency in deliveries where time, cost and quality are not consistent with contracts (Tilley, 2005). To balance the focus on the project uniqueness with the economies of scale created by standardization is a challenge. The purpose of managing design efficiently in housing is to generate the benefits of project repetitiveness without limiting the distinctiveness of client choices (Thuesen and Hvam, 2011).

Construction is identified as one of the largest engineer-to-order (ETO) sectors (Gosling and Naim, 2009). In an ETO context, the client enters the supply chain somewhere during the engineering phase (see Figure 1), enabling the client to affect the output, i.e. to customize the final solution. The engineer-to-order supply involves a non-physical stage that includes tendering, engineering and process planning activities, as well as a physical stage that comprises component manufacturing, assembly and installation (Sackett *et al.*, 1997).

With ETO in general, the product structure is deep and complex (more than six levels), which

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leads to a supply chain with many levels that tends to be unstable between projects (Bertrand and Muntslag, 1993). Systems building as a part of house-building can be interpreted as a predefinition of the engineering phase (see Figure 1), and leading to a predictable and stable supply chain. A stable supply chain enables the use of design management strategies (adapted from product development theories) with the goal to standardize technology and work processes (Jiao *et al.*, 2007a). In systems building, the supplier addresses this situation by forming a product platform. A product platform is an integral part of the value chain in a company (Robertson and Ulrich, 1998; Sawhney, 1998).

Robertson and Ulrich's (1998) definition of a product platform, containing the assets *components, processes, knowledge* and *relationships* is further developed and analysed in this research. Product development methods presented by Robertson and Ulrich (1998), and Meyer and Lehnerd (1997) are based on product platforms organized for large series production, using a make-to-order strategy (or those below in Figure 1). For house-building where the ETO strategy is used, one has to manage and repeatedly apply platforms in a series of projects in combination with unique client orders. The interface with the client is therefore of utmost importance.

Even though knowledge, rules and standards are stored in projects and people, Styhre and Gluch (2010) recognized the challenge of using platforms in their study of a Scandinavian construction company:

> … platforms are not very easily implemented in the construction industry since there is a strong instituted principle in the construction industry to avoid standardized solutions and off-the-shelf design of buildings. (Styhre and Gluch, 2010, p. 590)

By reusing solutions in sequential house projects, experience from design and production is gradually stored in the platform for future use (Robertson and Ulrich, 1998). The product platform is applied in the design phase, which makes engineering a crucial activity in confining the platform and preventing project-based development of new variants (Jiao *et al.*, 2007a). Different support methods, e.g. collaborative design (Senescu *et al.*, 2013), are used in housing design to manage a platform on a daily basis. The support methods can emphasize different platform assets, i.e. collaborative design supports knowledge and relationships, but does not build process knowledge.

As an indicator of the development and use of housing platforms, Thuesen and Hvam (2011) presented quality and lead time improvements as well as a reduction of project costs by 30% in a study of a German housing platform. The study embraced one platform on a 14-year base and would need further confirmation.

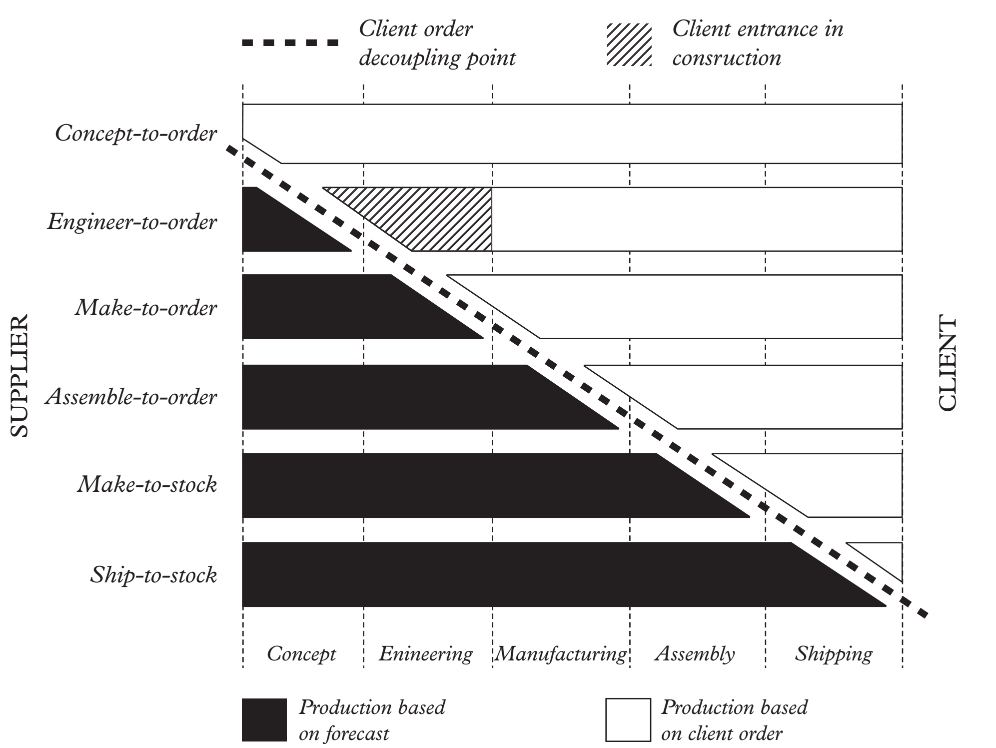

Figure 1 Visualization of the decoupling point between supplier and client (revised from Sackett *et al.*, 1997)

Because of the strong instituted principles in construction, it is important to study methods to support the use of a platform. Furthermore, the ETO situation would imply that there is a possibility for variation between systems building platforms in both the degree of predefinition and the focus in the supply chain. It is crucial to understand how the interaction between the application of support methods and the platform affects platform use in an ETO situation for systems building.

The aim is to understand and develop the product platform concept for the ETO situation exemplified by systems building, and to identify key factors that affect the use of platforms by analysing support methods and their application to platforms in daily engineering work.

Systems building using product platforms

Platforms

Robertson and Ulrich (1998) present a platform planning strategy, based on observations of the car industry, with design methods that balance customer needs with production costs. They define a product platform as follows:

> A product platform is the collection of assets [i.e. components, processes, knowledge, people and relationships] that are shared by a set of products. (Robertson and Ulrich, 1998, p. 3)

Following the line of the above definition, the platform affects product development, production and logistics processes, organizational structures and knowledge within the company managing the platform (Muffatto and Roveda, 2000). Meyer and Lehnerd (1997) supported the idea that the platform consists not only of physical parts, but also of process technologies and organizational capabilities.

By studying Black & Decker's and Hewlett Packard's product development in product platforms, Meyer and Lehnerd (1997) presented the Power Tower model (Figure 2) with the elements of: market instantiation by product families, product platforms nurturing several product families and the four basic assets serving as building blocks within a platform.

Platform assets

For large series of products, *components* are key elements while in the ETO context (e.g. construction or software business) component interfaces are central for project configurations (Thuesen and Hvam, 2011) and therefore the platform concept needs adaptation to specific contexts. *Components* are the physical building blocks used when designing a product and the related tools with manufacturing fixtures (Robertson and Ulrich, 1998). A focal point in Robertson and Ulrich's (1998) platform planning is the balance between *commonality* and *distinctiveness. Commonality* is the common base in the platform and the driver for simplicity and cost. Common parts

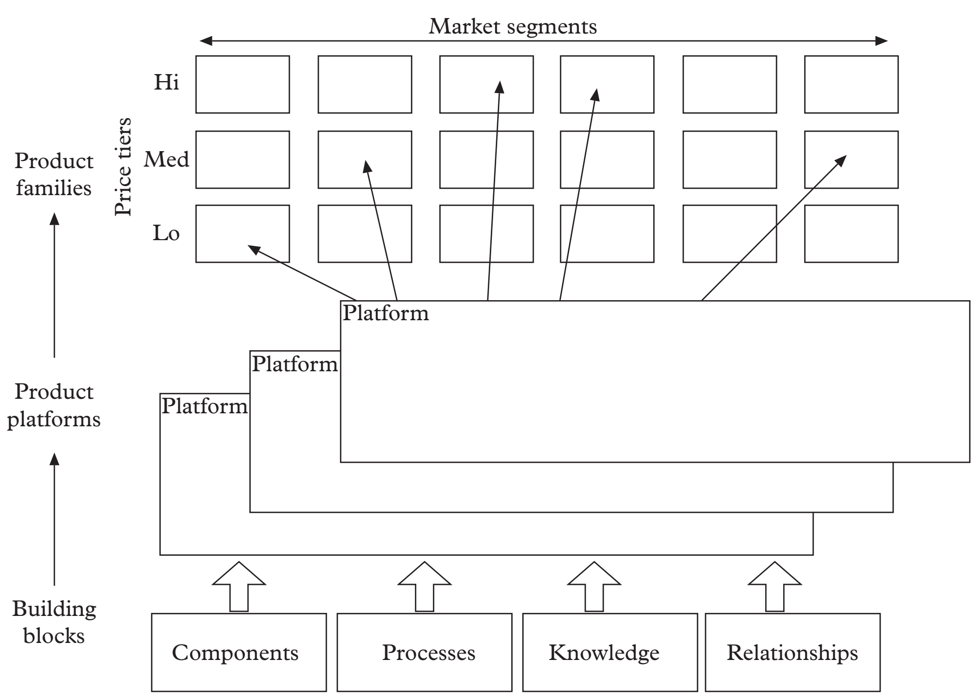

Figure 2 The Power Tower model of a platform (Meyer and Lehnerd, 1997)

appear in every product model produced within the platform. From a client point of view, the commonality in a platform provides no variation between models. When adding *distinctiveness*, the individual product uniqueness is created. To produce customized products efficiently, knowledge about production processes are gathered and refined to form the *process* asset of a platform. Process assets have a generic structure from which variations in diverse products and processes can be differentiated (Jiao *et al.*, 2007b).

According to Styhre and Gluch (2010), the *knowledge* asset is a mechanism for bridging between the stocks and flows of knowledge in construction organizations by integrating know-how and experience in activities. Knowledge sharing is a complex process and is practised in construction mostly by local networks and oral communication (ibid.).

Relationships initially concern people working on platform organization for product development. These people are organized in cross-functional teams with the task to either develop product families or to diffuse common solutions throughout the whole range of products (Muffatto and Roveda, 2000). Also relationships concern the relationships with other companies in the supply chain, where some actors are more closely coupled to the platform than others (Green *et al.*, 2005).

Support methods for platform use

Simpson *et al.* (2006) and Jiao *et al.* (2007a) further developed the product platform concept by adding methods for planning, decisions, optimization and configuration to support the engineering work. Their methods were found through summarizing literature in the field of product family development, and are used both for platform development and for configuration of product families to balance between client needs at the *front-end* of the supply chain and production costs at the *back-end* (see Figure 3).

The model for platform development incorporates iterations through the design of the product, the production process and the supply chain, based on axiomatic design theories (Suh, 2001), Figure 3. A predefined solution of these process steps forms a platform (ibid.), which is illustrated by Jiao *et al.* (2007a) in Figure 3: the predefined parts (the platform) are hatched (Jensen *et al.*, 2012).

Customization, configuration, production, supply and assembly are all activities in the process of defining the product that are supported by the platform. Research on applications that support the development of product families has been focused on configuration, e.g. agent-based or knowledge-based schemes for *back-end* decisions about manufacturing, production and logistics (Jiao *et al.*, 2007a). The front-end perspective focuses on innovation, higher performance, and lowering of client costs (Simpson *et al.*, 2006). Jiao *et al.* (2007a) argued that extended configure-to-order platforms (instantiated by guiding the client through a decision framework) could capture front-end issues and align them with back-end issues for product customization. Configure-to-order platforms are either ETO with a high degree of pre-engineering or make-to-order with a configuration process during sales. The platform development strategy is not successful in general; instead it requires the company to develop standardization for specific markets (Muffatto and Roveda, 2000). In housing construction there is a tradition of using different support methods for design in different projects and methods are often heuristic and chosen by project managers or by the design group.

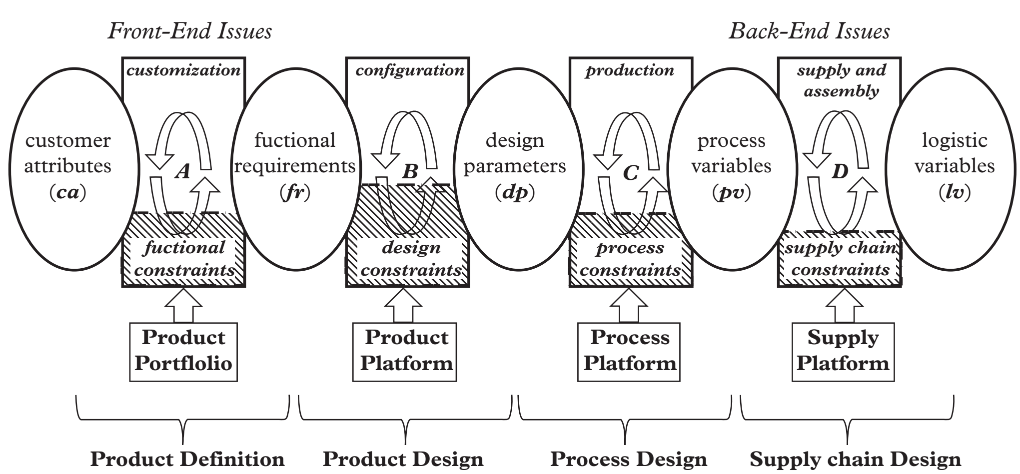

Figure 3 A holistic view of product family design and development (revised by Jensen *et al.*, 2012 from Jiao *et al.*, 2007a)

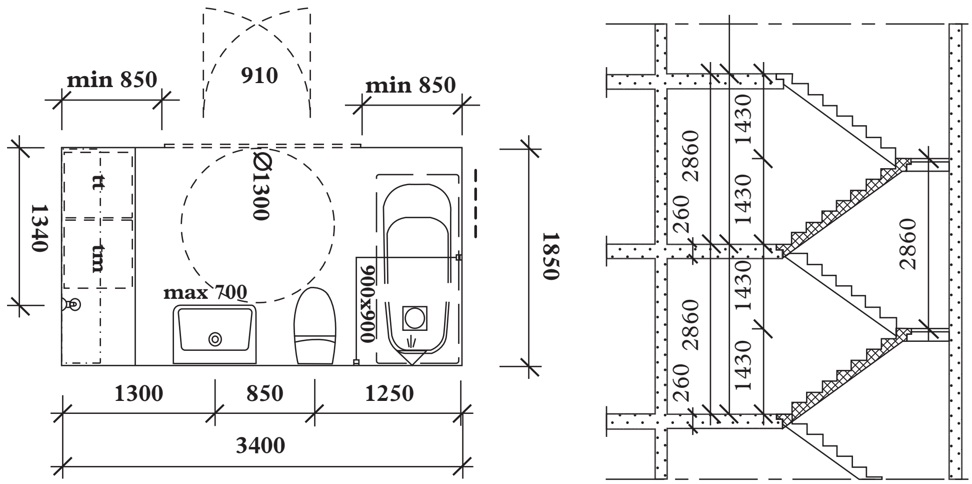

Figure 4 Data collected at the layout and detail levels, illustrating the component asset

The housing design context embraces communication within projects, sharing between projects, and knowledge generation across entire firms (Senescu *et al.*, 2013). When working as an engineer within a platform, your task is not to optimize the engineering work only, but also to balance your solutions for the success of the entire platform. Normally, this results in solutions that are non-optimal within a certain discipline, but the best possible for the performance of the platform. In Thuesen and Hvam's (2011) study of a platform for house-building in Germany, flow-based activity planning, combined experience/loyalty to standards, requirements handling, and value configuration were used as support methods to decrease costs and increase customer value from platform standards. The use of methods showed that a separation between platform development and use was needed to visualize the platform and to communicate internal trust in project implementation.

Design work in systems building

Design in systems building means transforming unique client-specific needs into houses that can be efficiently manufactured. By describing the relevant processes, according to a product range and its variety, in interoperable information systems, Persson *et al.* (2009) argued that efficient design management by systemizing the work could reduce costs and increase productivity. Engineering work is a part of the design phase where the platforms are configured to meet project variables. In a study of a Scandinavian contractor Styhre and Gluch (2010) recognize the platform as a tool of boundary objects that serves engineers with know-how, experience and other resources for effective work for the whole supply chain. The boundary objects (in instructions, blueprints, recommendations, etc.) should also allow local variations and individual creativity. Styhre and Gluch (2010) recognized that knowledge had the function to act as a bridge between accuracy and flexibility when combining the companies' boundary objects.

To improve housing design, discrete changes in technology and working practice can be part of the alignment between knowledge, capability, culture and management of control procedures (Roy *et al.*, 2005). In the context of construction projects, virtual design methods can be useful to manage components and technical solutions and to obtain pay-off from the repetitiveness in the product offer (Ekholm and Molnár, 2009). In systems building, when making a wholesale process commitment, design must manage not just the technical competence but also cooperative capabilities such as knowledge transfer, the ability to develop trust and meaningful negotiation, competencies in information processing, communication and intra- and inter-unit coordination (Johnsson and Andreasson, 2013).

Method

From the context of systems building and earlier studies of platform application in housing, the question of whether platforms can be straightforwardly applied to house-building was formulated. A literature study in engineering design and product platform theories in and outside the construction context formed a base for analysing the cases, i.e. the building design process at two different companies. The unit of analysis was the daily use of the platform through the application of support methods. By sorting the company activities in daily platform use and comparing them to platform theory, the conclusion was reached that the platform formulation suggested by Meyer and Lehnerd (1997) and developed by Robertson and

Ulrich (1998) did not really suffice in the ETO case. The adaptation to project-specific parameters was missing. This was achieved by the case companies through applying different support methods. From the results of the analysis platform key factors and a conceptual model for platform use in systems building were identified.

To understand the daily use of platforms in systems building, a study of two platform cases in construction was carried out: one case was an industrialized house-builder with offsite manufacturing (Company A) and the other, a large contractor (Company B) that works using industrialized methods. To create qualitative insights about platform use in housing design and identify factors governing the use of platforms, case study data were collected as a method of analysing qualitative phenomena (Miles and Huberman, 1994). Both Company A and Company B maintain control of the whole process. Two different organizations were chosen, not in order to create generalizability but rather to analyse the platform concept when it is applied to design from two different viewpoints. Company A is gradually opening up its platform for more customization, while Company B is in the process of finding its platform from a plethora of existing solutions.

Case study companies

Company A is an SME (small and medium sized enterprise) with an annual turnover of about €70 million per annum, active on the Swedish market, that has developed its platform to offer condominiums, rented dwellings, and senior housing based on prefabricated volumetric elements. The company was chosen for the study because of its use of a standardized product platform for housing where the design team has rigid requirements for fast and correct deliveries to an automated manufacturing line. Design management was studied over a five-year period with 52 projects providing input data. Interviews and observations were conducted over two time periods in 2008 and 2011.

Company B is one of the four largest contractors on the Swedish construction market with a turnover for housing of about €800 million per annum. Different product platforms are built up in order to support the entire company with standards for housing, infrastructure and commercial buildings. The company was chosen because the projects that are internally developed with wholesale process control have design support methods applied to them. Company B differs from Company A as it does not have any automated production in a factory, but constructs its buildings using traditional onsite production. The five projects studied at Company B generated findings about process, knowledge and relations in daily engineering work during the period 2011–12. The four support methods *design planning*, *collaborative design*, *design optimization* and *requirements iteration* emerged from the two case studies. These methods were used to analyse the support of platform engineering work in an ETO situation in order to find key factors for platform use in systems building.

Data collection

Quantitative data were gathered from documents, the business systems at the companies and the predefined rules expressed as templates in computer aided design (CAD) and customer relationship management (CRM) systems. In total, 1613 documents distributed in components (649) and processes (964 design, purchasing, and construction activities) were categorized from both companies. The knowledge base and the relations in the form of organized team set-ups and long-term contract formalization were gathered from a total of 62 documents.

By choosing semi-structured interviews to collect the contextual data at the companies, the respondents were able to freely describe their view of design support methods (Flick, 2009). The interviews validated quantitative data collected in the form of written platform documentation. During interviews with respondents at the companies, the central documents and standards for the product platform, along with instructions for platform use, were identified and described. At Company A, interviews were carried out on an operational level with two project managers and two structural engineers. Because design and prefabrication are centralized, with short internal communication paths, interview questions were asked about operational engineering work and related methods that support platform use.

Eight interviews were planned and carried out at Company B with both strategic (two platform managers, two business managers) and operational staff (two project managers, two structural engineers) in order to capture platform use from a wide point of view. To verify data sources (Miles and Huberman, 1994) and obtain a clear picture of company design work from a platform perspective, two method developers and two additional operational project managers were interviewed after data analyses of the documents. All interviews at both companies had guiding questions followed by open-ended questions to allow the respondent to describe the platform topic from different perspectives (Miles and Huberman, 1994). The purpose of this structure was to capture platform granulation and understand the focus of support methods in relation to the data collected from the documents.

Analysis

Platform assets and support methods for design in systems building were analysed to identify factors and understand platform use in an ETO situation. The data about the platforms were grouped by the first author into components, processes, knowledge and relationships in order to identify the level of commonality and focus within the platforms. The results are shown in Tables 1 and 2 with calculation of the percentage of commonalities for the component and process assets in the building projects studied. This is illustrated in Figure 5, where the hatched area indicates commonalities for a particular asset. The engineering support methods were also analysed to categorize them (Miles and Huberman, 1994) as supporting flow and/or client orientation in Tables 3 and 4. Finally, how the support methods focused on front-end or back-end issues was analysed using the theory of platform use (see Figure 3). Here it was discovered that the actual existence of support methods in design violates the platform concept as visualized by Meyer and Lehnerd (1997). Therefore, a tentative model, Figure 6, was suggested as valid for the ETO situation where support methods are used as a means to produce distinctiveness instead of the product family concept.

Case study results

Both companies are in a phase of development of their systems for a specific supply chain, using different organizational resources but describing the same goals: to meet client needs with profitable production. The companies have captured their platforms in documentation that describes commonalities for components (technical systems) and processes (design, manufacturing, supply chain). Unique solutions for client customization are managed in the engineering phase by either applying a platform option or developing a new solution that fits the platform. Company A has a clear focus on the structural system

Table 1 Distribution of component standardization in platform documentation

Predefined components	Structural framework	Windows & doors	Balconies & façades	Room specification	Corridors & stairwell	HVAC & plumbing	Electricity	Roof structure	Groundworks & foundation
Company A	134 (47%)	36 (13%)	22 (8%)	56 (20%)	11 (4%)	10 (4%)	3 (1%)	11 (4%)	0 (0%)
Company B	46 (12%)	27 (7%)	29 (8%)	93 (24%)	13 (3%)	49 (13%)	88 (23%)	21 (6%)	17 (4%)

Table 2 Distribution of process standardization in platform documentation

Predefined activities	Design	Purchasing	Offsite production	Onsite production
Company A	187 (33%)	98 (17%)	115 (20%)	171 (30%)
Company B	251 (63%)	49 (12%)	0 (0%)	98 (25%)

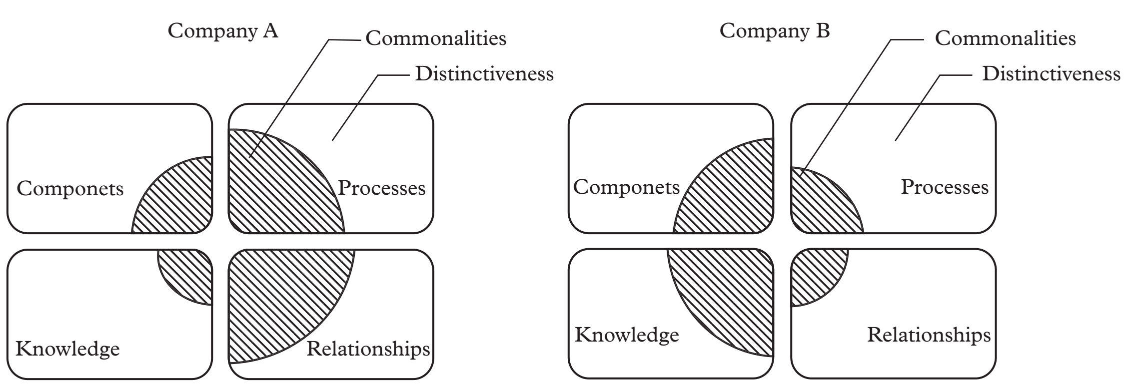

Figure 5 Distribution of platform documentation

in the platform with a few rigidly defined component/system commonalities (see Table 1). Furthermore, some spaces are standardized in the floor plans, e.g. bathrooms and student accommodation spaces. Company B has distributed its documentation of the platform standard more evenly across the four constituent parts of the platform (Robertson and Ulrich, 1998). However, Company B emphasizes room descriptions and heating, ventilation, and air conditioning (HVAC) solutions based on CAD models and written documentation, with a high level of detail on how to create production deliverables.

By combining product and process standardization on how components, technical sub-systems and systems should be produced, both companies have standardized their work to differing degrees with a clear strategy of achieving productivity. Company A, using a higher proportion of offsite manufacturing, has defined work tasks down to component level, complete with work routines for offsite production. Company B has defined its processes as activities and routines, both in its business system and in written procedures. Neither of the two case companies has documented all their design and production activities. Onsite standardized work is less documented in comparison to offsite and design work at both companies.

Knowledge about both technical systems and processes is documented in Company B and is stored in its enterprise resource planning (ERP) system in order to achieve transparency between building projects. Company A has documented its knowledge base in routines together with product and process standards, but does not make use of an ERP system. The experience feedback in daily work updates production knowledge which in turn provides feedback to the engineering phase. The experience feedback is documented but is less analysed (Johnsson and Meiling, 2009).

Long-term contracts with suppliers and subcontractors have been set up by Company A to help it predict the flow and increase precision for the whole supply chain. Three defined design teams manage between six and nine projects in parallel, to feed the factory with deliveries in the form of drawings, descriptions and data. The speed of the engineering phase for Company A is planned according to a fixed production flow in the factory. Company B, which does not have a factory, strives to keep the same set-up of participants through the design phase. In spite of this, in Company B changes of actors often occur because of long cycle times. Typically 25–50 weeks are spent in the engineering phase for the case study projects. The design teams in Company B frequently use multidisciplinary interaction in the later part of the engineering work. Company B separates product and process standardization in its platform and has more documented routines in the engineering phase to control its organization than Company A. Company B has no long-term contracts with suppliers, but procures them for every project.

For both companies, undefined distinctiveness is a major part of their platforms, which then has to be managed in the design phase. Some variants creating distinctiveness are defined for components but fewer or none describe process, knowledge, and relation distinctiveness.

Support methods for platforms

Construction design has become more fragmented with specialization and this puts demands on the *design planning* to manage both the business and project domains. Planning is carried out from a pull-perspective at Company A where a lean production approach is under implementation. The production flow in the factory affects the pace of engineering work and therefore the design activities and deliverables have been deconstructed in a work breakdown structure (WBS) with the associated delivery times. The delivery times are checked at daily meetings. This has led to an increase in engineering work speed with a nominal average time frame of 16 weeks per project.

Company B, which offers a wider range of structural solutions than Company A uses a more traditional construction engineering work method combined with visual support methods. Owing to the long-term deadlines (often 6–12 months for the engineering phase) and the use of a site-based production set-up, time planning uses tolerances.

Collaborative design is used to match the speed between production and engineering in Company A and is applied in all projects. The design team meets on a daily basis, checking and adjusting the deliverables following the set time plan. The time plan has been broken down to identify commonalities in the platform based on activities in the engineering phase. This forms the base in design planning and provides a common language for succeeding with collaborative design.

Collaborative design at Company B is used to validate deliveries and ensure constructability. The design team meets weekly in a special design room using a set agenda to discover, analyse and monitor project problems. Much of the work revolves around virtual models displayed during the meeting as a base for discussion. The design time is not substantially reduced but according to interviews, more problems are solved before production using *collaborative design*.

Design optimization is used by both companies to store and communicate continuous improvement and client satisfaction through knowledge that is highly critical to the companies' survival. Company A has an operational approach through daily feedback where deviations are reported and handled to increase quality in deliveries within its platform but also to continuously improve it. The overall idea is that the feedback reports should be analysed and changes implemented to the engineering work process. This is only partially functioning, since the engineers receive many feedback reports and they state that there is no time to incorporate all of them. Company B uses central expertise to streamline and optimize the use of platform standardization with a focus on components. This optimization follows a defined plan, which is followed up later in the design phase. The experts continuously define and develop the platform from experience and knowledge derived from audit data and production costs.

Requirements iteration is practised at Company B in some projects where experts on energy usage, acoustics and fire are invited early on in the engineering phase in order for the company to make use of positive iteration for technical solutions that adhere to platform standards. Requirements iteration is an inseparable part of design in the various phases of construction projects where the engineering work is done by iterating drafts until the design parameters for different systems are locked. The use of requirements iteration in the platform is related to the management of commonalities for solutions like ventilation systems, balcony solutions and plumbing systems. Company A also uses technical expertise in areas such as structural engineering, energy usage, acoustics and fire but only in the later phases of engineering; it relies on rules in the standardized platform for early design. According to the project managers, no requirements iteration is performed at Company A unless the manufacturability of the platform is violated.

Analysis

Analysis of support methods

The support methods were chosen to support design work at both case study companies. Tables 3 and 4 describe how the four support methods focus on different platform assets at Company A and Company B. A stronger focus by using a method on a particular asset results in darker shading; lighter shading indicates weaker focus.

The support methods employed at Company A have a clear back-end focus on production and supply chain issues using the method *design planning*, which combines resources from the design and production phases. The use of routine processes gives opportunities for speed in the process (Jiao *et al.*, 2007b) where Company A, through its coherency in organization, has developed connections from general processes down to task level. The back-end focus is also shown in the *collaborative design* where platform commonalities in engineering activities enable a faster flow through the design. Company A bases its *design optimization* on platform performance feedback which is used as a project input at the beginning of the design process. It relies very little on methods that invite the client to follow the process, e.g. *requirements iteration*. This indicates a lower client focus in the design process at Company A than in Company B.

Company B has developed a front-end focus on client requirements using *collaborative design*, inviting the client to participate in the process. *Requirements iteration* is practised at Company B, where the method supports matching platform-based solutions to project requirements. Focus is put on technical solutions

Table 3 How the support methods in design focus on the platform assets at Company A

Company A	Design planning Back-end focus on planning the process	Collaborative design Back-end focus on planning the process	Design optimization Back-end focus on feedback to optimize process	Requirements iteration
Component	Parts delivery scheduling	Securing manufacturability	Daily feedback reports and documentation	Not practised
Process	Detailed activities and deliveries plan	Daily meetings, flow-oriented	Daily feedback with platform improvements	Not practised
Knowledge	Pull-based project dependent planning	Activities sorted in commonalities and distinctiveness	Continuous improvements separate from the design process in projects	Not practised
Relationships	Long-term, fixed relations	Fixed relations and predefined deliveries	Operational feedback on behaviour and deliveries	Not practised

Table 4 How the support methods in design focus on the platform assets at Company B

Company B	Design planning Back-end focus to find correct solution	Collaborative design Front-end focus to solve client problem	Design optimization Back-end for component, front-end for knowledge	Requirements iteration Front-end focusing component requirements
Component	No focus	Model-based clash detection	Centralized hierarchical documents	Functional requirements to design parameters
Process	Sub-process planning, deliveries plan	Weekly meetings, quality-oriented	Discrete events, reflection twice in every project	Iterations of requirements through design
Knowledge	Push-based project planning	Problem solving by technical experts	Centralized documents issued in versions	Early expert involvement
Relationships	Varying relations between projects	Project organization, unstable over time	Feedback from strategic level	Client, suppliers and technical experts

(components), which are designed using client requirement input. *Design optimization* together with *design planning* have a back-end focus on cost, planning and commonalities in components, containing tested knowledge and organized to increase the use and development of the platform.

Collaborative design, *requirements iteration* and *design optimization* are methods that not only tailor the specific platform assets to project parameters but also manage the transformation of the client demands in the front-end to the production and supply chain in the back-end of the building process. Applying support methods can emphasize different assets in the platform. *Design planning* supports drafting deliveries and documentation of processes while *requirements iteration* supports the gradual discovery of an answer. To define platform rules in construction, the identification of commonalities requires combining design and manufacturing processes for components (Thuesen and Hvam, 2011).

Platform use in the ETO situation

The support methods applied by the case study companies are meant to support the daily use of the platform. These are currently not part of the theoretical description of a platform (Robertson and Ulrich, 1998; Simpson *et al*., 2006). Platform use in an ETO context must allow for project commonality and distinctiveness, given the project organization and its inherent content of a mix between standard and customized solutions (Roy *et al*., 2005). Because the context is ETO without the use of fully predefined products, the platform assets are not defined in product families before an order, which contradicts Meyer and Lehnerd's (1997) view of platform organization. Each project replaces the use of product families.

The engineering support methods have to support the use of defined commonalities and yet allow creative design for both onsite and offsite construction. The support methods are used to bridge the gap between the standardized platform and the project-specific parameters. As an example of bridging, some component blocks are standardized as commonalities in the platform, so Company A uses timber-framed modules and Company B standardizes storey heights and floor spans. Both technical systems rely on engineering to match these commonalities to a project's unique site layout and building footprint by the use of support methods.

As a tentative model for the function of platforms in the ETO situation, the structure shown in Figure 6 is proposed. The product platform in Figure 6 is based on the same four assets *components*, *processes*, *knowledge* and *relationships* as defined by Robertson and Ulrich (1998). Predefined commonalities for each of the four assets are stored within the platform, i.e. components and activities from Tables 1 and 2. Instead of combining commonality and distinctiveness parts into product families, support methods are used to combine platform commonalities with project distinctiveness (Figure 6). The distinctiveness parts of the platform are not fully predefined, but can be affected by the client during the design process and are handled by the support methods so as not to violate platform use.

In essence, Figure 6 is a variation of the original platform definition by Meyer and Lehnherd (1997) and Robertson and Ulrich (1998).

In an ETO context, the knowledge of the product itself needs to be complemented with structured knowledge, i.e. the process and knowledge assets, on how to develop project dependent variations that still remain inside the platform, thus not compromising downstream efficiency. As shown in Tables 3 and 4, both companies are knowledgeable in support methods. Tentatively, platforms used in an ETO context

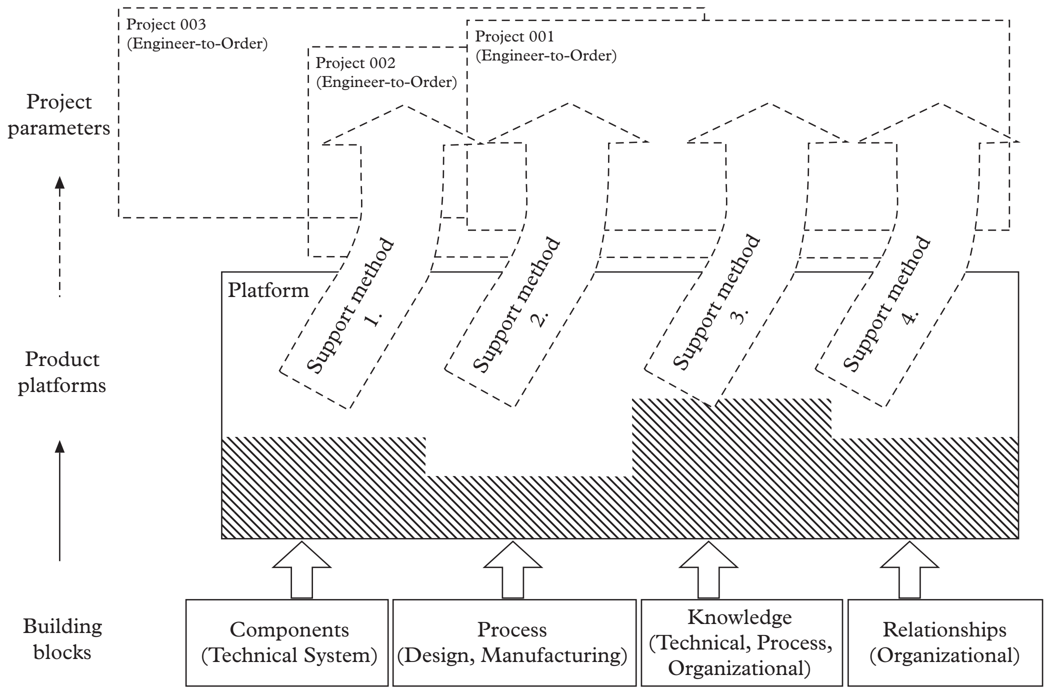

Figure 6 Proposed platform model for an engineer-to-order supply chain

would need a stronger focus on knowledge than found in a make-to-order context.

The two companies differ on one interesting point. Company A has integrated the supply chain and therefore has a stronger focus on processes that are connected to components in its platform. Company B, on the other hand, works with (the more common) fragmented construction supply chain, procuring subcontractors for each new project. Company B therefore has a stronger focus on the product, since the process knowledge downstream is somewhat out of its control. Company B has instead focused on front-end issues and uses *requirements iteration* in the early design phase. Company A has higher predefinition in its platform and has chosen to skip practising *requirements iteration*.

Company A has concentrated standards in its platform focusing on the structural elements used in factory production and support methods that address *back-end issues*. Company B has a fragmented platform approach with support methods and platform standards for both *front-end* and *back-end issues*. A similarity between the two companies is the focus on the documented platform standardization and support methods, but on different assets (components and knowledge for Company B; processes and relationships for Company A). Both companies leave the engineers unsupported in some parts of the design process. By allowing engineers to solve client requirements (front-end) without support methods there is a risk that unique project-specific variations in the platform may slowly cause it to degrade (Senescu *et al.*, 2013).

In both companies, platform development is an ongoing process and support methods could be complemented by standards within the platform for more defined products for specific markets. Since the development of platforms is rigidly connected to the daily engineering work in a project organization, the separation into pure platform development is needed to control investments and progression Thuesen and Hvam (2011).

Discussion

Engineering work in housing design makes the client a natural part of the design process—a more gradual decoupling point than visualized in Figure 1. The platform constitutes what the supplier must adhere to, to complete production. Hence client requirements are drivers for the unique parts of the platform and all platforms in construction need a unique part, due to the decoupling point.

The ETO context with changing client demands hinders a fully parameterized platform. From the cases studied, support methods are used by suppliers to handle the distinctiveness in partly defined platforms. The choice of support methods would be an area that needs further study and development. The importance of choosing a certain support method is unknown.

Company A has chosen to document its design process in segmented standards for offsite production and manages a supplier-led platform focusing on back-end issues and is constrained from opening up production for a wider market. There is a risk of engineering work taking over the focus on client needs. In a situation where employees enter the company, having component and knowledge assets undefined would lead to a slower uptake of platform knowledge, thus leading to a decrease in efficiency.

Company B on the other hand operates a client-driven platform which is able to solve front-end issues and is thus able to address different market segments but pays through longer lead times caused by back-end issues (Jiao *et al.*, 2007a), with fewer documented processes and relationships. A fragmented, partly standardized platform does not yield economies of scale because of the lack of connection between component and process standardization (Simpson *et al.*, 2006). In the ETO situation with a gradual decoupling point, knowledge about client needs becomes essential for planning engineering work and realizing the possibilities to configure platforms that match the production and supply chain for each housing project. In platform planning in systems building, choosing *how* to standardize (focus on specific parts, e.g. the structural frame or work across the entire supply chain simultaneously) should have the highest priority. The case study result showed that interfaces between platform assets are difficult to define, where isolation of standardization resulted at both companies.

Conclusions

Design support methods for daily engineering work are needed when using platforms in an ETO context in order to bridge gaps between project requirements and platform parameters. Meyer and Lehnerd's (1997) model of a platform (Figure 2) cannot be applied straightforwardly by ETO companies but needs to be amended with a project-specific part with related support methods, to be able to maintain platform core values (Figure 6).

Separation between platform development and platform use is difficult in an ETO context even in systems building. Although it is possible to carry out product development outside projects, it is not always feasible since not all client needs are predictable, but arise when project requirements meet platform parameters in the engineering phase. From the case studies and the analysis, *platform assets*, *categorization*, *distribution* and *focus* are key factors describing a platform:

- The platforms used in systems building have been shown to contain the assets of components, processes, knowledge and relationships as proposed by Robertson and Ulrich (1998).
- Commonalities and distinctiveness are useful categories in platforms for ETO, regardless of technical systems and the supply chain structure.
- Product families are not a useful category for all systems building. Instead, project-specific parameters can be handled through support methods yielding distinctiveness. The ETO context hinders full parameterization.
- The distribution of commonalities and distinctiveness affects platform use and usefulness. The assets can be distributed unevenly; with Company A they focus the structural frame, while with Company B the approach so far has resulted in isolation of standards.
- Platforms and support methods in an ETO situation can focus on back-end (the supply chain) or front-end (the client) issues. Support methods within the same platform can have either back-end or front-end focus.

Also, the organization and choice of support methods are relevant to the work with developing platforms. Further studies in the field of platform performance measurement could give companies valuable guidance for support method investments.

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