

Article

Artistic and Engineering Design of Platform-Based Production Systems: A Study of Swedish Architectural Practice

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Abstract: Research on platform-based production systems for house-building has focused on production and manufacturing issues. The aim of this research is to explore how the architectural design process contributes to the industrialised house-building industry from the perspective of creative design work. It also aims to describe how constraints affect architectural design work in the engineer-to-order context, when using platform-based production systems. Architects with experience in using platform-based building systems with different degrees of constraints were interviewed regarding creative aspects of the design work. The interviews, together with documents relating to platform constraints, were then analysed from the perspective of artistic and engineering design theories. The results show the benefits and issues of using platform constraints, both with prefabrication of volumetric modules, as well as prefabricated slab and wall elements. The study highlights a major research gap by describing how architectural work, from both the creative artistic and engineering design perspectives, is affected by constraints in the building platform: (1) the architectural design work goes through a series of divergent and convergent processes where the divergent processes are explorative and the convergent processes are solution-oriented; and (2), there is a trade-off between creativity and efficiency in the design work. Open parameters for layout design are key to architectural creativity, while predefinition supports efficiency. The results also provide an understanding of the potential for creativity in artistic and engineering work tasks through different phases in design, and how they are related to constraints in the platform. The main limitation of the research is the number of interviewed architects who had different background experiences of working with different types of platform constraints. More studies are needed to confirm the observations and to understand how creativity and efficiency interact with divergent and convergent design processes.

Keywords: architect; platform; creativity; constraints; house-building; design stages

1. Introduction

Industrialised house-building has a history of focusing on production values, using engineering methods to control quality and production issues. Standardisation of design work in house-building has, for the last twenty years, focused on production, economics, and sustainability, with energy reduction and flow efficiency considered especially important [1,2]. The Swedish timber house-building industry, with a tradition of prefabricating single-family timber houses, has derived its current market share based on platform-based production systems for multifamily houses. In the last two decades, the industry has developed platforms for multi-family timber houses to meet demand, resulting in a market share of about 15% in 2017. The industry has plans to expand to 50% of the market share by 2025 [2]. Multi-family house projects, from two to eight storeys, for the business-to-business (B2B)

market, have taken advantage of using predefined timber elements, but have also used concrete-based platforms to improve the building process, resulting in lower costs and higher quality through better control of the production chain.

Industrialised house-building companies offer a range of building processes, from high levels of constraint to fully customised projects [3,4], both for on-site or off-site prefabrication production. The range of constraints of the product affects the management of the construction design process and imposes constraints for architectural work in the early stages. Here, industrialised house-building companies have organised the design into a standardised, flow-oriented process to support the platform-based production system [2,4,5], whereas creative design tasks have to fit into the standardisation of platform and processes. Although in recent years more attention has been given to customisation and the architectural design of industrial house-building platforms [1,6], the architectural expression of functional solutions and aesthetic values has diverged from production-oriented prefabrication [6]. Architectural expression has also struggled to establish and maintain architect-led prefabrication in systems with a high level of design automation [7]. Smith [8] suggested that architects are not trained for design automation that focuses on increasing market share instead of elegant artistic solutions. Davis [7] described how certain architects resist prefabrication, while other architects accept it; Davis related this disparity to the development of modernists in the early twentieth century.

In house-building, as one of the largest engineer-to-order (ETO) sectors [9], clients enter the process somewhere in the design phase. From a creative perspective, the design process is a combination of artistic and engineering work, where architects both try to meet their client's intentions and goals, while simultaneously focusing on delivery. The tension between artistic and engineering design becomes routine for an architect, both in the practical tasks and the expectations of their role in house-building projects [10]. In the early design phases, where not all the parameters have been set, requirements, iterations and the efficient management of the flow of information are of great importance to the economics of house-building projects [11]. ETO platforms with few constraints (so-called open platforms) have a design normally based on traditional project-based iterations between client, architect, consultants, and the contractor. Platforms closer to a make-to-order production system (so-called closed platforms) have fewer degrees of freedom, hence fewer design parameters that need to be processed by the stakeholders in the design process [4].

Most studies to date have focused on the engineering design (e.g., [5,12–14]), whereas only a few studies of the architectural objectives in the context of industrialised house-building have been published (e.g., [5]). To analyse the architectural design work from a creative perspective, valuable knowledge of the use of platform-based production systems and their constraints will be provided. Therefore, the purpose of this study is twofold:

- First, to explore how architectural design work contributes in engineer-to-order production of industrial house-building projects;
- Second, to understand how the creative perspective in the architectural customisation process of platform-based buildings is affected.

The paper is structured as follows: first, there is a short review of creativity and artistic design versus engineering design of industrialised house-building platforms; next, the methodology of the study, unit of analysis and selection of respondents is then presented before the results are analysed. The paper ends with conclusions of the study and proposals for future research.

2. Theory

2.1. Creativity in Design Processes

Intellectually challenging tasks have the potential to increase creativity [15,16]. If turned into an everyday chore (routinisation with constraints), there is a risk of reduced intrinsic motivation, which might lead to fewer creative solutions to problems [15,17]. For example, constraints can refer

to the fact that a creative work has been commissioned (as opposed to not being commissioned), that instructions are controlling (as opposed to informative), or that the creative individual feels controlled or constrained in their daily work environment (as opposed to feeling autonomous [18]). These kinds of constraints have been shown to negatively influence creativity [18]. The design process for house-building includes functional constraints and site conditions to manage, whereas architects have different strategies for their design work. Some focus on functional analysis of client demands and calculated information, while others focus on the geometrical modelling first, to analyse functional constraints and site conditions [19]. However, too few constraints can result in high complexity, leading the designer to reuse ideas to make the task more manageable, thus reducing the level of creativity [20]. Creative solutions are often easier to reach when the problem is described in detail, though the degree of creativity might not be high. Instead, if the problem is explored and discovered by the creative individual, the time and effort spent is likely greater, but the results can end up having a higher degree of creativity. Csikszentmihalyi [15] described this differentiation as a continuum, where problems can be presented or discovered to varying degrees.

2.2. Artistic and Engineering Design Work

The tension between artistic and engineering design has been discussed from the design process perspective (e.g., [10,21–23]), where artistic design objectives include aesthetic expression, user functionality, emotional value, and semantic or symbolic value [4,10]. Engineering design is described as a mainly linear process, with some iterations between process steps [21,24]. Artistic design, on the other hand, is described as a cyclic, spiral process where cognitive processes are the focus, rather than the sequential progression, of the project [21,23,25]. An important point to note is the engineering perspective to strive for a structure that manages their design processes [10], which can be one explanation for the linearity of the consensus model [26]. For artistic designers, such control is often regarded as inhibitory rather than quality-improving [27,28]. Hence, the consensus model of artistic design does not strive to standardise and control the design process, but rather to increase the understanding of what makes design processes more or less successful [21]. Descriptions of the engineering design process aim to make a complex process tangible and transparent, by structuring the process through stages of analysis and synthesis. Each stage provides ever more concrete descriptions of the solutions [24]. The process is described as sequential but is not meant to be rigidly interpreted [24]. It should be used as a guideline, adapting it to each design situation by removing or reorganising process steps. The output of each step is used as the basis of the subsequent step and allows analysis of design suggestions against the initial (but evolving) requirements [21,24]. The architectural design process is often described, from an engineering design perspective, with four main phases: pre-design, concept design, design development, and construction documents. According to Howard et al. [26], some engineering design models promote both divergence and convergence, where idea generation is followed by integrated evaluation and selection of ideas (i.e., convergence). However, Le Masson et al. [10] argued that the majority of engineering design theories promote mainly convergent thinking methods. In architectural design, both conceptual ideas about the building's appearance and thoughts on functional properties need to be developed. These two perspectives are, according to Peponis et al. [28], developed in parallel, using conceptual ideas based on a combination of divergence and convergence design. In artistic design, divergence is key to exploring design possibilities alongside the problem definition [10]. However, convergence is also necessary and integrated as a natural part of the process, to synthesise feasible ideas into something that is possible to implement and present [27,29]. Green and Bonollo [27] suggested a phase-based design process description for industrial design and product development. However, Lawson [23] questioned this sequential representation, arguing that an artistic design process is built up of cyclic iterations between analysis, synthesis, and evaluation, developing the problem definition along with the solution suggestions. He claimed that problems call for iterations between the general and the detailed solutions. Details can often be part of the initial idea generation and creative conceptualisation. Although

Lawson [27] distinguished the differences between an engineering design task and an artistic design task in terms of distinctiveness, he argued that most designers “deal with both precise and vague ideas, call for systematic and chaotic thinking, and need both imaginative thought and mechanical calculation”. According to Javid [30], sketching is used to evolve design ideas gradually from vague, tentative concepts into detailed representations of design suggestions and embodiments of how the designer perceives and intends to solve the design problem.

There is a clear distinction between engineering and artistic design work, where the engineering design problem is often described using a tree structure, with sub-problems and their sub-sub-problems being specified before synthesising design solutions [21]. The focus of the design task is on physical performance, whereas artistic considerations (such as aesthetic details) are usually not prioritised [21]. Artistic design problems, on the other hand, are seen as ill-defined, open-ended problems where problem definition and problem solutions emerge parallel to one another [10,21,22]. A similar distinction to the one between engineering design and artistic design work has been made in creativity research. To achieve high levels of creativity, designers should be allowed to reflect on, and influence, the problem definition [12,28,31]. Well-specified problems that are presented to a designer, with little autonomy regarding the content of the task, are probably easier to solve but result in outcomes that are less creative [10].

2.3. Platform-Based Design Work in Industrialised House-Building

When designing houses, design processes vary in time and complexity. The use of platform constraints for cost-efficient production of multi-family houses has increased significantly in the Swedish building industry [3]. The ETO production environment means that not all building requirements are set before the client enters the design phase, and that the platform constraints become a part of the overall design requirements in the customisation process [2]. Constraints in platform-based building systems are defined with requirements for components, processes, and organisational relationships in the ETO production system [6]. Jallow et al. [11] identified the importance of requirement management throughout the project lifecycle, with traceability of changes and transparency of requirements between stakeholders in paperless information systems for the effective coordination of design changes. In the transformation of functionality requirements and demands to product solutions, the combination of space objects and physical objects can carry requirement information through the design process [32,33]. Component constraints in platforms vary from being predefined and fixed, to flexible combinations of variable modules using open parameters [13,14]. Constraints of components range from smaller parts, to apartment layouts, to building dimensions [5]. Dimensions are a central platform constraint, but shape, material, and colour are also parameters that could vary in the component platform. Control of aesthetic features in facades and of building dimensions is problematic in the design phase [34], so constraints aim to reduce design time and to secure quality and buildability of the output from the design process. While component constraint focuses on physical aspects (i.e., constraints of height, repetitions, or modularised components), space constraints often describe the functionality for space use, air flow requirements, or production units [2]. Process platform constraints were described by Jansson et al. [5] as predefined work in the building process for on-site and off-site production, but also in the design and review process. Routinisation of tasks is documented for both internal or external actors, to optimise time and collaboration in the building process [3]. For industrialised house-building contractors, the constraint of organisational relationships covers both internal links with suppliers as well as links in the tendering for contracts. Thus, relationships with architects, clients, and consultants are a key factor for collaboration in the building process [2].

Through history, architects have been divided into practitioners that prefer and make use of predefined constraints for prefabrication, and those who see prefabrication as a hindrance. Davis [7] suggested that architects and the construction industry have not taken advantage of each other's professions, and thereby not developed at the same pace as other industries. By exploring architects'

experience of using platform constraints, the question of how industrialised house-building influences and limits their work can be explored. Through that question, it is interesting to increase the knowledge about how the design processes for artistic and engineering creative tasks depend on the range of constraints in house-building platforms.

3. Methodology

This study of architects' incorporation of platform-based production systems in their design processes followed a qualitative research design based on interviews and data analyses of archived projects and platform drawings. Archived project and platform documents and drawings were collected in collaboration with one house building company in Sweden (Lindbäcks AB). Interviews, as a research method, are appropriate when researchers want to investigate how respondents perceive and assign meaning to certain events [35]. Hence, interviews were chosen as the main data collection method to explore the design work of a platform-based production systems. First, interviews with structural and platform managers were carried out to understand and diversify different levels of platform constraints. The interviews with architects were semi-structured, having predefined questions about how the architects perceived their work when having platform constraints in projects, and about how they perceived their creative work and architectural design processes. The conversations were, however, still allowed to take different forms, depending on the respondents' answers (so-called in-depth interviews). In this way, an exploration of the subject could occur without first defining a (too narrow) unit of analysis [36] that would have limited the understanding of the design processes and their contextual settings. To describe artistic and engineering design processes that used platform-based building systems, six architects who had experience in working with a variety of predefined systems for multi-family houses for the Swedish market were selected for the study. Five of the interviewed architects had worked with prefabricated volume modules (see Figures 1 and 2) and three with prefabricated concrete elements such as beams, floors, and walls.

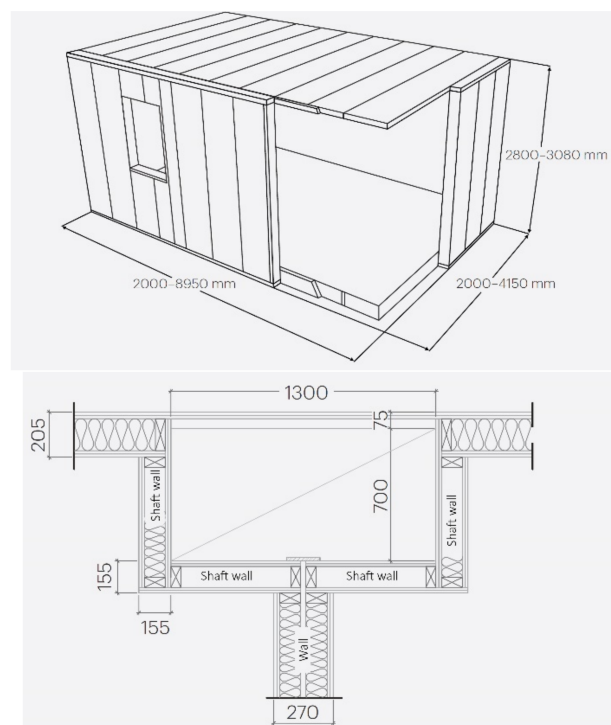


Figure 1. Examples of constraints in platform-based building systems (volume module and shaft geometry). (Figure courtesy of Lindbäcks AB).

An interesting part of the design process was the way in which the layout of the building was created when using a volumetric building system that the house builder had produced (Figure 2). Based on platform constraints from the house builder, architects form the shape of the building in the layout matching process. The layout matching process was described in interviews as matching constraints in the building system with layouts that met the demands and requirements of the house builder and the client. Here, the matching process was within the scope of the study, along with how prefabrication affects the way architects can create aesthetic features.



Figure 2. Layout matching to platform constraints with a volume building system (figure courtesy of Lindbäcks AB).

The architects who responded were selected from a mixture of ages, genders, and locations in Sweden, and had experience in working with different house-building companies. The major problem of establishing the reliability of the results is describing the link between the studied case and the version described by the researcher [36]. To minimise misunderstanding between interviewees and the aim of the study, the main concepts of platform-based building systems, design phases, creativity, and constraints were used as a basis for the interviews. The case study offered the opportunity for analysis and deeper understanding, by applying different theoretical perspectives to the studied context [35]. The case study was limited in how to use constraints in different design phases of house-building. By analysing creativity in architectural work, along with artistic and engineering design theories, and by using experiences of platform-based production systems as the unit of analysis, architectural design work could be explored and understood. This also gave the opportunity to describe how platform definitions affect the architects' ability to express themselves artistically in their daily work. The qualitative approach of the research suggests that the final results should lead to working propositions rather than conclusive findings [35]. Subsequent research can then strengthen or contradict these propositions, thus, further developing our understanding of the theoretical constructs.

During this study, it was more interesting to have in-depth interviews with a smaller group of experienced architects to explore and understand design work. Exploration and understanding are, therefore, more related to this study than generalisation and explanation.

4. Results

4.1. Architectural Use of platform-Based Production Systems

In general, the architects interviewed were positive about their use of platforms in the design process. The main constraints they experienced were not because of limitations in the platform, but because of economic considerations and imposed requirements from the client in the development of architectural objectives for the building.

Those with more experience in working with platform-based constraints were generally more positive regarding the impact on the design process. Four of the six architects described the creativity involved in solving design issues to be as inspiring as solving puzzles. Those with less experience in working with platforms found that the predefined dimensions of elements restricted their architectural creativity and their ability to incorporate aesthetic quality. All architects believed that the use of platforms had potential when routinely producing good quality elements efficiently. However, they also felt that, in the future, there was the potential to improve the shape, creativeness, and functionality of architectural elements in platform-based design processes. All architects clearly felt that the use of platforms had improved the production process without putting too many constraints on the design of houses for the mid-range market in Sweden. However, three of the respondents felt that more focus should be put on the expression of the building and the surrounding environment instead of the production process.

Architects often described the requirements in house-building projects as being focused on economics, restricting the creativity that architects could express using the platform. Predefined structures, stability, and energy requirements were often discussed early on, constraining aesthetics in the pre-design and conceptual design phases. Some of the platform constraints followed municipality regulations, but the programming constraints in pre-design were seen as major obstacles to creative design. Full freedom over requirements was seen as challenging, demanding a longer design process to achieve successful results. The Swedish building regulations for housing act as requirements for the early phases in design, particularly the availability rules and environmental regulations for the design of houses. A common observation was that few client functional requirements were related to a low project budget, and requirements for retirement housing and hotels were more complex to handle using platform constraints than residential and student apartments. Here, it was advocated that the design manual of the house-building platform should not only cover functional requirements, but also include general dimensions and constraints in the production system.

Those who worked with volumetric systems identified constraints when using predefined components for production efficiency. For the exterior aesthetics, roof gutters and windows were identified as major issues, along with orthogonal restrictions and module lengths, potentially restricting creativity in the early design phases. Bathroom modules have become a central part of standardisation in some platform-based production systems. Their specific, predefined layout allow for the use of vertical shafts, and to speed up drying time during manufacture. The architects expressed the need for flexible dimensions of bathroom modules in volumetric and prefabricated concrete element systems. Component dimensions for prefabricated concrete slab systems sometimes restrict the design, and knowing how to match installation disciplines to the use of platform constraints becomes challenging when aiming to speed up the design process. Also, it is sometimes difficult to work with fine tolerances and achieve global benefits. In general, the architects' experiences of using concrete element systems were positive; they described how the architectural design was supported by structural calculations, flexibility in modular dimensions, and creative opportunities in the façade aesthetics.

Regarding process constraints, the interviewed architects felt it was easy to start a design if the process was standardised. Before the creative design work could start, there was a need to understand how the design process related to production processes, and how different technical production constraints should be handled. One architect described their learning from production preconditions as: “What a machine can do and what a man can do.” All architects described how early presentation of dimension constraints resulted in a better design process. When the design process involves constraints of detailed production solutions, architectural variety is restricted, which is often the part of the process that handles aesthetic values and allows exploration of the design for ways of solving functional requirements. Those who worked with volumetric modular systems and had to follow a predefined process, 28 weeks before production, felt free to create within the layout matching process. However, they often felt excluded from the detailed design process, with limited collaboration during the 16 weeks before factory production.

A general conclusion of the architects was that organisational relationships always play a key role in how much architectural creativity can occur in projects. Contract forms, client and contractor goals, team structure, and team competence are all crucial to creating dialogue with project architects, which can improve outcomes. The architects gave several examples of how important the combination of colours, façade shapes, and components are for the total appearance of a building or residential area. The communication between contractor, consultant, architect, project managers, and the client is especially important when working with predefined systems and processes. This is true not only for production reasons, but also to achieve long-term goals that benefit society and improve usage. The architects concluded that descriptions of production methods in the early design phases helped to create successful projects both in terms of production cost and architectural creativity during the process.

4.2. Architectural Design Process with Platform-Based Constraints

The design work with platform constraints includes sketching on a large scale, focusing on the building’s setting, adapting the design to constraints from the volume building system, and functional analyses of spaces for apartments, down to product detailing, among other activities. In the process, the architects switch between large-scale and detailed design, working towards their vision of the end-product. In the design phase, architects work with a catalogue of solutions and space combinations in mind, both when using volumetric modules and component systems, to match client demands for buildings.

“Sometimes a rough outline is needed to help push things along, but often the underlying process needs to wait for all the inputs to be defined. House-building platforms may be a necessity, both to provide an acceptable speed of manufacture and a reasonable cost.”

The architects all described how design can be a smooth process if the client has already decided how to produce the building, and efficient if constraining parameters for production are communicated early. A predefined process does not constrain architectural work, but decisions by the client often result in a long response time when processed on the client side. The task is to interpret the client’s wishes and demands and analyse them from different perspectives. The less experience the client has in working with constraints in platforms, the more requirements appear to change during the design process.

All the architects interviewed agreed that, when describing architectural objectives, it was important to start with the functionality of the product and space requirements and iterate solutions before production variables dominated the process. The phrase “first define what to create and then how to do it” dominated the overall process description. In the early design phases, it is important to communicate what is possible with each platform. The architects described how to gain inspiration when using platforms with constraints. They would walk around old and new areas and carry out scale-based volume studies, drawing a number of perspectives in different layers.

The architects described the issues with closed platforms and how hard it was to fit these designs into the surrounding environment, while fulfilling the functional requirements. Their experience with totally fixed dimensions in closed platforms was that such companies try to sell their products with the words: “It is just stacking them, and it is going to be great.”

According to the architects, customisation of such platforms often results in projects running over budget and buildings that are not fully suitable for site conditions and the end user. While an open platform constrains module dimensions or element prefabrication, closed platforms with fixed dimension products allow no freedom for the architect to create functionality, such as space and light quality, that can enhance the building. When working with open volumetric platforms and component systems, architects described the work as complicated but also inspiring, a challenge to solve.

“Having full freedom, it may seem quite amazing, but it’s very frustrating too. You have to know what you want to create; you have to decide on something. If you do not have a platform, you have to create your own platform to define the task. So, in a way, it’s always nice to have a framework and some suggestions”.

In a similar way, the architects described how, following state regulations, it was very rare that two buildings became identical when using platform-based production systems. The design of a building relies on the detailing of both interior and exterior space. Aesthetic design in architecture is sometimes difficult to achieve when using constraints in platforms, but may not be important when creating functional housing, according to the architects. Exterior designs using platform constraints rely on façade materials and the use of element interfaces. Here, the architects did not agree about solutions. Some liked to take the properties of the original material and interface and exaggerate their attributes, while others preferred to hide them with different façade systems, even if that was not a priority of the house builder. The architects described how projects in different locations and lack of other buildings create diversification in architectural design. A building’s orientation in relation to its surroundings is one key aspect for clients.

“It’s a lot about how to group buildings; it’s not just laying them out. Rather, when you are building a residential area, it is the relationship between the houses, the courtyards and the spaces they create. It’s almost the most creative work I would say, to understand how people move, where children should play and where you could find shelter from wind and sun”.

Creativity when using platforms is described as a different kind of creativity, with constraints but without “having to reinvent the wheel”. One part of the work is in the development of new, creative, and detailed solutions that could work with platform constraints in future projects. Efficient design was often the outcome from using a platform or prefabricated components. Architects disagreed as to whether creativity was enhanced through inspiration, or whether creativity was reduced the more projects used platforms. Designing using platforms could be inspiring, since architects could learn different production processes, learn to use pattern-based layouts, and learn to resolve challenges created by location-related requirements. Using a predefined platform for timber volumetric modules imposed constraints on the length and height of room combinations, while the use of concrete elements restricted the number of competences required to design for functionality.

The results show the benefits and issues of using platform constraints, both with prefabrication of volumetric modules, as well as prefabricated slab and wall elements. Results from the study highlight a major research gap by describing how architectural work, from both the creative artistic and the engineering design perspectives, is affected by constraints in the building platform. The result also provides an understanding of the potential for creativity in artistic and engineering work tasks through different phases in design, and how they are related to constraints in the platform.

5. Analysis of Artistic and Engineering Design Work Using Platform Constraints

The architects described design work as being able to create something new and surprising, presenting solutions that people would not predict. In the early stages of creative design work with platform-based production systems, the focus is on functional requirements. These include both internal requirements determined by the platform (such as constraining dimensions), as well as other requirements (such as regulations or site conditions). Many researchers have recognised divergence as important in a creative process, since it enables the exploration of new solution paths [10], helps to generate ideas, and promotes thinking from many perspectives [27,29] to fulfil requirements. Results of artistic design vary according to how great the effects of the platform constraints are on the design in the early stages. Fixed façade design, roof gutters, and layouts all hinder artistic work. Understanding platform constraints is often difficult, particularly when there is little time and significant pressure to produce results. In the pre-design and concept design stages, architects followed a cycle of analysis, synthesis, and validation, which was central for matching layouts in creative design. In these phases, design work was more a cyclic process than a sequential one (see Table 1). When designing using many predefined constraints applied to requirements and components, and with a standardised design process, the architect can start with modelling and designing in a smooth linear process, as described by Javid [30]. It is up to the architect to manage the requirements along the way and communicate changes to the client when necessary. Thus, divergence work can be essentially influenced by the structure of the design processes [26]. Convergence work has also been shown as important to a creative process to synthesise and evaluate ideas [10,20,26,29]. With respect to divergence and convergence when using constraints, convergence occurs when many ideas or possibilities are synthesised towards a single design [27,29]. In our study, this convergent iteration was noted as occurring in both pre-design, to describe objectives, and in the design of aesthetic features and detailing. Convergence is linked to cognitive thought processes [27]. Where an industrialised house builder has routinised tasks for the design development and construction documentation phases [3], the creative process becomes task-based rather than solely cognitive [25]. This study shows that house builders use constrained solutions and technical interfaces not for gaining benefit in the early stages of pre-design and concept design, but for managing design developments, speeding up design detailing, and the entire design process for efficient product deliveries (see Table 1). Architects can use a platform for the layout matching process and still create artistic space solutions, at the same time as matching functionality for room, areas, and the building itself to client demands. In the concept design phase, architects describe how to lock unconstrained parameters using creativity when using the platform-based building system.

Table 1. Creative work from a process perspective.

Creative Work	Design Process	Architects' Experiences
Cyclical to understand	Pre-design	Understanding platform constraints Analysing surrounding requirements Describing objectives
	Concept design	Managing large-scale platform constraints Matching layouts for functionality Describing creative functional solutions
Managing to create	Design development	Using detailed platform constraints Collaboration for faster design Describing detailed solutions
Sequential to explain	Construction documents	Developing efficient deliveries Routinisation of platform tasks Describing the platform product

Using platform constraints does not necessarily result in a straightforward task. Some constraints may contradict one another, whilst others may be challenging to solve, thus increasing task complexity, increasing the need for divergence, and generating a sense that the task is intellectually challenging [17,20]. Routinising the platform design process places an onus on the architect to be flexible in their creative work and to justify their detailed solutions. If the constraints help to clarify project goals, it is likely that positive synergies enhance creativity [18], which is also relevant for a discussion of how creativity is expected to occur in a design task.

The convergent design tasks that benefit from platform constraints occur in the design development phase, where the work can be planned as sequential tasks and with parallel disciplines. Architects are key players at this stage, according to the interviewees, fixing parameters and explaining and visualising solutions for functional requirements. Following the engineering design process (according to Cross and Roozenburg [21], and Pahl, Beitz, Feldhusen and Grote [22]), the latter part of design development and the construction documentation phase are both flow-oriented towards production and often exclude or minimise architect involvement in terms of applying creativity to improve deliveries and reduce costs (see Table 1).

Following the views of Davis [7] and Smith [8] of a separated architecture profession, the study shows how experienced architects have accepted and use the platform-based production systems for innovations in shaping and design, while new users are frustrated over dimension and production limitations. In the same way, new users are valuable to the industrialised house-building industry because, as critical users, they can help enlarge design possibilities within the industry.

6. Conclusions and Further Research

This study furthers the understanding of architectural creativity using platform-based production systems, based on engineer-to-order production, in two ways. The first conclusion concerns how architectural design work contributes to the engineer-to-order production of industrial house-building projects:

- #1: *The architectural design work goes through a series of divergent and convergent processes in the design of platform-based production systems.* The divergent processes explore the understanding of problems, such as client and site requirements and platform constraints at different levels of detail. The convergent process occurs when the ideas are synthesised into proposals to describe design objectives, functional requirements, and in the design of aesthetic features and detailing.

Depending on how projects are predefined in respect to requirements and constraints, both by site conditions and by the platform, the number of divergent and convergent iterations varies with how much is predefined. Both divergent and convergent processes are important in the design of platform-based production systems. The divergent processes are important for exploring the boundaries of the platform constraints in the specific project, whereas the convergent processes support the efficiency of the engineering design.

The second conclusion concerns the creative aspects of architectural design using platform-based production systems:

- #2: *There is a trade-off between creativity and efficiency in the design of platform-based production systems.* Open parameters for layout design have been identified as one key to architectural creativity when using platform constraints, while predefined components and/or volumetric modules both support efficient design processes by routinisation during design development and construction documentation.

The study shows how creativity can vary through the design process where high level constraints challenge the architect to design layout solutions in a limited space and where fewer constraints and open parameters give more freedom allowing the architect's creativity to manifest itself. The creative work of artistic and engineering design, identified in this study, shows the importance of understanding

the production process for architects, and the involvement of architects in industrialised house-building processes to meet future demands for aesthetics and functionality that satisfy end-user and client values and requirements.

This qualitative study has investigated the architectural design process using a limited number of Swedish industrialised house-building platforms. More studies are needed to confirm the observations from this study and to understand how creativity and efficiency interacts with divergent and convergent design processes. Also, research is required into how architects' experiences could be incorporated more into the specific development of platform constraints for engineer-to-order building systems. This knowledge can then be utilised in the design of platform constraints for engineer-to-order building systems in order to facilitate the architectural divergent and convergent processes throughout the different design stages.

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References

1. Aichison, M.; Macarthur, J. *Prefabricated Housing in Architecture*; Book Chapter in *Offsite Architecture: Constructing the Future*; Routledge: Abington, UK, 2017.
2. Brege, S.; Nord, T.; Stehn, L. Industriellt byggande i trä—Nuläge och prognos mot 2025. *Res. Rep.* 2017. Available online: <http://www.diva-portal.org/smash/record.jsf?pid=diva2%3A1153498&dswid=4918> (accessed on 21 February 2018).
3. Lessing, J.; Stehn, L.; Ekholm, A. Industrialised house-building: Development and conceptual orientation of the field. *Constr. Innov.* **2015**, *15*, 378–399. [[CrossRef](#)]
4. Lidelöw, H.; Olofsson, T. The Structure and Constraint of the Industrialised Construction Value Chain. In *Proceedings of the 2016 International Conference on Construction and Real Estate Management*, Edmonton, Alberta, Canada, 29 September–1 October, 2016.
5. Wikberg, F.; Olofsson, T.; Ekholm, A. Design configuration with architectural objects: Linking customer requirements with system capabilities in industrialised house-building platforms. *Constr. Manag. Econ.* **2014**, *32*, 196–207. [[CrossRef](#)]
6. Jansson, G.; Viklund, E.; Lidelöw, H. Design management using knowledge innovation and visual planning. *Autom. Constr.* **2016**, *72*, 330–337. [[CrossRef](#)]
7. Davis, D. *The Prefabricated Home*; Reaction Books: London, UK, 2005.
8. Smith, R.E. Connect Homes: Modular Housing Patent and Architect Led Business Model. *J. Archit. Educ.* **2016**, *70*, 168–171. [[CrossRef](#)]
9. Gosling, J.; Naim, M. Engineer-to-order supply chain management: A literature review and research agenda. *Int. J. Prod. Econ.* **2009**, *122*, 741–754. [[CrossRef](#)]
10. Le Masson, P.; Hatchuel, A.; Weil, B. The Interplay between Creativity Issues and Design Theories: A New Perspective for Design Management Studies? *Creat. Innov. Manag.* **2011**, *20*, 217–237. [[CrossRef](#)]
11. Jallow, A.K.; Demian, P.; Baldwin, A.N.; Anumba, C. An empirical study of the complexity of requirements management in construction projects. *Eng. Constr. Archit. Manag.* **2014**, *21*, 505–531. [[CrossRef](#)]
12. Kiviniemi, A. Requirements Management Interface to Building Product Models. Doctor's Thesis, Stanford University, Stanford, CA, USA, 2005.
13. Bonev, M.; Wörösch, M.; Hvam, L. Utilizing platforms in industrialised construction: A case study of a precast manufacturer. *Constr. Innov.* **2015**, *15*, 84–106. [[CrossRef](#)]
14. Jensen, P.; Lidelöw, H.; Olofsson, T. Product configuration in construction. *Int. J. Mass Cust.* **2015**, *5*, 73–92. [[CrossRef](#)]

15. Csikszentmihalyi, M. *Creativity—Flow and the Psychology of Discovery and Invention*; Harpercollins Publishers: New York, NY, USA, 1996.
16. Shalley, C.E.; Zhou, J.; Oldham, G.R. The Effects of Personal and Contextual Characteristics on Creativity: Where Should We Go from Here? *J. Manag.* **2004**, *30*, 933–958. [[CrossRef](#)]
17. Choi, J.N.; Anderson, T.A.; Veillette, A. Contextual Inhibitors of Employee Creativity in Organizations: The Insulating Role of Creative Ability. *Group Organ. Manag.* **2009**, *34*, 330–357. [[CrossRef](#)]
18. Amabile, T.M. *Creativity in Context: Update to “the Social Psychology of Creativity”*; Westview press: Boulder, CO, USA, 1996.
19. Yu, R.; Gu, N.; Ostwald, M. Comparing Designers’ Problem-Solving Behavior in a Parametric Design Environment and a Geometric Modeling Environment. *Buildings* **2013**, *3*, 621–638. [[CrossRef](#)]
20. Caniëls, M.C.J.; Rietzschel, E.F. Organizing Creativity: Creativity and Innovation under Constraints. *Creat. Innov. Manag.* **2015**, *24*, 184–196. [[CrossRef](#)]
21. Cross, N.; Roozenburg, N. Modelling the Design Process in Engineering and in Architecture. *J. Eng. Des.* **1992**, *3*, 325–337. [[CrossRef](#)]
22. Eder, W.E. Engineering Design vs. Artistic Design: Some Educational Consequences. *US-China Educ. Rev. A* **2013**, *3*, 259–280.
23. Lawson, B. *How Designers Think—The Design Process Demystified*, 4th ed.; Architectural Press: Oxford, UK, 2005.
24. Pahl, G.; Beitz, W.; Feldhusen, J.; Grote, K.-H. *Engineering Design: A Systematic Approach*, 3th ed.; Springer: Berlin, Germany, 2007.
25. Howard, T.J.; Culley, S.J.; Dekoninck, E. Describing the creative design process by the integration of engineering design and cognitive psychology literature. *Des. Stud.* **2008**, *29*, 160–180. [[CrossRef](#)]
26. Green, L.N.; Bonollo, E. The Development of a Suite of Design Methods Appropriate for Teaching Product Design. *Glob. J. Eng. Educ.* **2002**, *6*, 45–51.
27. Runco, M.A. *Creativity: Theories and Themes: Research, Development and Practise*; Elsevier Academic Press: Amsterdam, The Netherlands, 2007.
28. Peponis, J.; Bafna, S.; Dahabreh, S.M.; Dogan, F. Configurational meaning and conceptual shifts in design. *J. Archit.* **2015**, *20*, 215–243. [[CrossRef](#)]
29. Tan, A.-G. Convergent Creativity: From Arthur Cropley (1935-) onwards. *Creat. Res. J.* **2015**, *27*, 271–280. [[CrossRef](#)]
30. Javid, A. Creativity in Architecture Design Education: Design as Puzzle Solving. *Int. J. Des. Educ.* **2014**, *8*, 11–21. [[CrossRef](#)]
31. Mumford, M.D. Managing creative people: Strategies and tactics for innovation. *Hum. Resour. Manag. Rev.* **2000**, *10*, 313–351. [[CrossRef](#)]
32. Jansson, G.; Johnsson, H.; Engström, D. Platform use in systems building. *Constr. Manag. Econ.* **2014**, *32*, 70–82. [[CrossRef](#)]
33. Brege, S.; Stehn, L.; Nord, T. Business models in industrialised building of multi-storey houses. *Constr. Manag. Econ.* **2014**, *32*, 208–226. [[CrossRef](#)]
34. Gjerde, M.; Vale, B. Aiming for a Better Public Realm: Gauging the Effectiveness of Design Control Methods in Wellington, New Zealand. *Buildings* **2015**, *5*, 69–84. [[CrossRef](#)]
35. Yin, R.K. *Qualitative Research from Start to Finish*; The Guilford Press: New York, NY, USA, 2011.
36. Flick, U. *Managing Quality in Qualitative Research*; SAGE Publications: London, UK, 2007.

