LUND UNIVERSITY

Configuration with architectural objects in industrialised house-building

Wikberg, Fredrik; Ekholm, Anders; Jensen, Patrik

Configuration with architectural objects in industrialised house-building

F. Wikberg[1], A. Ekholm[1] and P. Jensen[2]

[1]*Design Methodology, Department of Construction Sciences, Lund University, Faculty of Engineering,*[2]*Technical University of Luleå, Sweden*

ABSTRACT: The construction industry is facing the dilemma of simultaneously reducing costs and increasing quality. An increasing control and standardization of processes and products is strived for, while at the same time regarding customer and society requirements for architectural variation. Industrialised building and development of house building platforms are examples of this development. The research presented here shows a way to analyze the results of the development of a platform for a multi-storey house building system, specifically with regard to the flexibility of the platform. The analysis is based on the use of architectural objects as design interface in different design levels. The method is shown to complement the traditional QFD methodology, and shows the relative dependence of design decision levels.

1 INTRODUCTION

1.1 *Demands for industrialisation of the building industry*

The building industry, in Sweden and internationally, has not shown the same development in productivity and industrialization as the manufacturing industry and the sector has been criticized for quality failures and high costs (ECTP 2005, Egan 1998). An industrialization of the industry has been pointed at as a measure of meeting these problems (Byggkommissionen 2002). Different strategies have been developed in order to make the industry more efficient (Lessing 2006). Off-site manufacturing and systems building has a long tradition (Gann 1996), while Strategic partnering (Miles 1996), Lean construction (Berthelsen 2004), and BIM (Eastman et al. 2008) are recent developments with this purpose.

Customers want tailored, distinctive products, while costs are driven by commonality (Robertson and Ulrich 1998). Modularization strategies in product development making use of Quality function deployment methodologies is a way of tackling variety in a technical platform (Akao 1990).This study is specifically directed towards design methodology and platform development in the context of modularization and systems building.

1.2 *Background, problem, and objective*

Design based on a technical platform may be done in a so called configurator allowing parametric design of the building system's components within the framework of the determined platform.

In our previous research, we have introduced the idea of architectural object as a new concept according to which the configurator is built. Such a configurator allows the designer to explicitly work with user activities and experiences related to the building while at the same time adhering to the restrictions of a technical platform. The problem addressed in the research presented here is to structure the design process for a multi-storey house building system, specifically design decision levels and their respective dependence using architectural objects as design interface.

Previous papers on the subject of architectural objects (Ekholm and Wikberg 2008, Wikberg and Ekholm 2009) have defined and explored the concept of architectural objects in industrialised house-building. In this paper we deal with the possibility of using architectural objects as a support for a modular product development process using Quality function deployment methods. Establishing a holistic view of the product through matching specific technical requirements of modules with general functional requirements in architectural objects may prove to be a viable way.

1.3 *Research questions*

Could the concept of architectural objects and design levels be used to structure the design process of a multi storey house building platform and act as a link between design requirements and the develop-

ment of technical modules to improve the technical module versatility in different situations?

2 PRODUCT DEVELOPMENT AND ARCHITECTURAL OBJECTS

2.1 *Product development and systems building*

Production in a market economy is adapted to customer demands. The customer often a has choice between different products. Systems building is often associated with low-cost concepts and poor environments. Studies in Japan show that systems building in combination with low-cost concepts are not as successful as more recent quality focused concepts (Noguchi, 2003). At the same time a number of surveys show that if companies want to face the market competition it is important to adapt to different customer demands through a variety in the product offers (Hofman et al 2006). An intended focus on controlling process and production factors with a simultaneous customer focus is therefore of central importance already during the initial product development phase. Examples may be collected from lean (Morgan & Liker 2006) and agile product development (Anderson 1996). Common ingredients are approaches towards mass customization, standardization and modularization in order to quickly adjust to the market.

However, to achieve architectural quality more than production control and customer focus is of necessity. In a recent discussion by (Beim et al 2009) architectural quality is understood to encompass the building's properties, their coherence, and its value as perceived by its users including in the widest sense citizens. Flexibility is pointed out as one of the most important properties of the building platform and the built facility. To conclude, building design has two separate but related rationales, 1) the technical/business oriented, and 2) the architectural, concerned with values for users in the widest sense (Rönn 2001).

2.2 *QFD – translating customers needs into product*

Designing products that are focused on customers needs is essential to sustain competitive advantage. In product development the mapping of customer needs (requirements) against product properties are important, and well defined methods have been developed in the manufacturing industry. The most frequently used is called Quality Function Deployment, QFD (Akao 1990). It is used a means for introducing customer needs early in the design process. When the customer requirements are defined a House of Quality matrix (Cross 2000) can be formed and the weight of relationships between product properties determined. The work of finding customers requirements and turning them to product properties are often done by a QFD-team were all disciplines are involved. In the construction industry's traditional procurement systems, implementation of a QFD methodology may be difficult, since different actors are responsible for different parts of the project, and "cross-functionality" is hard to achieve. Industrialised house-building may however offer new possibilities of using QFD, since a single organisation is responsible for the whole process and functional requirements can be defined at an early stage (Dikmen, Birgonul, Kiziltas, 2004) .

2.3 *Modularization approaches*

A way of meeting the customer demands for variety is to create flexible product platforms. A product platform is defined as a product architecture including a set of subsystems and interfaces based on a core strategic vision (McGrath 1995).

A way of reducing complexity but still offering customized solutions is through modularization. Modularization is a way of decomposing a product into building blocks (modules) with specific interfaces, driven by company specific reasons (Erixon 1998).

Customers want tailor made, distinctive products, while costs are driven by commonality (Robertson and Ulrich 1998). A key issue in a platform planning process is balancing commonality with distinctiveness. Robertson and Ulrich are using a Differentiating Attribute (DA) as a way to denote what customers find important in distinguishing between products. The term chunk (module) is used for a major physical element of a product that could be shared among products to exhibit high levels of commonality.

Their fundamentals for platform planning and described relationship between the value of differentiating attributes to customer and the increasing cost for variety of chunks could also be used in the context of systems building. Advantages with standardized and rationalized product structures, makes it possible to customize flexible solutions (Ulrich and Eppinger 2008).

Using the Modular Function Deployment (MFD) method for modularization (Erixon 1998) is one way of tackling the problem of defining this product structure open to customization. In this method cus-

tomer requirements and specific design requirements are handled by using QFD analysis. Technical solutions that meet certain demands are developed and turned into modules. Through identifying and evaluating module drivers new concepts and technical solutions are evaluated. Identification and evaluation of module interfaces is an important factor for which concept to select. Modules can later on be improved without affecting other parts and modules of the product. The design or development of modules can be supported further with methods like Design for Manufacturing and Assembly (DFMA) (Erixon 1998) or the Design for Variety Method (Martin and Ishii 2002). Attempts to reduce complexity of customized systems buildings through adaptation of methods like QFD and MFD from the manufacturing industry are promising (Jensen et al 2008, 2009).

2.4 *Design for variety*

A way of developing a product platform architecture is presented by Martin and Ishii in their Design for Variety method (DFV). Their step-by-step method makes use of a series of indexes to develop a decoupled architecture that could minimize design efforts for future generations of a product (Martin and Ishii 2002). The first index used is a General Variation index (GVI), derived from estimations of component change over time. A QFD structure with two phases are used where input customer requirements matched onto engineering metrics (EM) give requirements on physical components. The estimated EM targets based on customer requirements could however be more or less likely or costly to accommodate. The matrix used and judgements taken into consideration gives EM values estimating the external drivers for change. These could be rated and summed up as GVI values for each component estimating the amount of redesign needed. The external drivers also cause internal coupling effects among components, that must be controlled in a robust product architecture. Calculating the coupling indexes (CI) are therefore of vital interest. The methodology aims both at being a descriptive method, through aquiring GVI and CI values, but also be prescriptive through presenting adequate actions. The DFV-method helps out in developing a product architecture that incorporates [the right amount of] standardization and modularization to reduce future design costs and effort (ibid 2002).

As the earlier mentioned methodologies as QFD, House of Quality and Design for Variety prescribe, it is important to find methods for isolating the variety to those parts that are most likely to change due to different external causes. In the context of house-building it is primarily customer preferences that are a key driver for changing the technical system parts or modules defining the product platform.

2.5 *Modular approaches in Dutch house-building*

When describing product architecture it is possible to make a distinction between modular and integral product architecture (Robertson and Ulrich, 1995). In product development for systems building problems may arise, as it is of importance deciding to what extent technical parts or modules either affect each other or the function of the product as a whole. Ulrich defines a product architecture from (1) functional elements (2) the relation between functional and physical (technical) elements, and (3) the specification of the interface between interacting physical elements. It is therefore seldom that a categorization of parts as common, standardized or compatible (Wolters 2001) at the same time could be related to both a specific technical function and a specific user function.

In the specific setting of the house-building industry Veenstra, Halman and Voordijk (2006) have practised this theory and presented a methodology for developing a product platform architecture based on the Design for Variety (DFV) method that take into account the customer preferences in a modularization process. Their approach is to group technical elements into user related functional modules that through adding, substituting and/or removing may instantiate different product family members (Veenstra et al. 2006).

The result for a company is a decoupled architecture that can offer a variety of customer choice and still require less design effort for follow-up products. Through grading customer preferences based on a profound vignette study on the importance of variation in housing attributes (Hofman, Halman and Ion, 2006) and matching these results with the design of the decoupled 'customized' modules the coupling of the built elements are thoroughly investigated. The impacts of expected and changed customer requirements are reflected in a generational variety index (GVI) and in estimated coupling indexes (CI). The latter determines where to put focus, whether part of a design could be standardized or should be modularized in order to meet changing demands.

The methodology developed by Veenstra et al. is only applied for single-family houses, but seems applicable also in a context of multi-family housing. However, an increased number of modules and more complex interrelation between different levels of detail (structure and in-built modules) or design phases may urge for a supplementary approach to decision-making in the design process. As pointed out by Veenstra et al. their specifications of structure modules and inbuilt modules apply to the Open Building ideas of support and infill (Habraken et al. 1974) and could in this respect be developed further, whereas: 'Open Building [also] aims at a situation where decisions made at upper levels leave the contents of the decisions made at lower levels open'.

In this respect we find it interesting to test our approach with Architectural objects and design levels (Wikberg and Ekholm, 2009), in conjunction with DFV, and the methodology for developing product platforms for the house-building industry presented by Veenstra et al.

2.6 *The level order of design of the built environment*

The built environment is generally thought of as organized in different levels of design or "intervention" (Habraken et al. 1974, Habraken 1982 and 1998, Ekholm 1987). The level order reflects both the artifacts' size and other aspects, and the organization of social systems in different control levels, see Table 1.

Table 1. Levels of control, built elements, and actors in the system man-built environment.

Control actor	Controlled built elements	Control level
City authority	Infrastructure (streets, sewer etc)	City, neighborhood
Building management	Building related building elements	Building
Building user organization	Organization related building elements	User organization space
Building user	Activity related building elements	Activity space

The idea is that a social system in a lower level may control activities and artifacts that do not interfere with social systems in higher levels. On the other hand, a social system in a higher level may control activities and artifacts that restrict the freedom of action and possible configuration of artifacts in a lower level. This leaves a relative freedom of decision making on lower levels within a framework set in higher levels.

Applied in the context of building design, the general idea is that design decisions concerning construction entities and building elements in higher levels of control constitute a framework that restricts the possible decisions about building elements in lower levels of control.

For example, the possibilities to raise partitions in an existing building are restricted by the extension of its external walls and floors. A design process could be described as an iterative sequence involving several levels where decisions on one level, involves analyses of possibilities and consequences in other levels. The levels of control or decision making do not restrict the use of the built environment. An activity may involve parts of the built environment belonging to several different levels of control.

According to our theory the constraints for each sublevel object is given by its superior objects. This also applies an order of design configuration.

2.7 *Situations and architectural objects*

In an earlier paper we have presented a theoretical background for our concept of "situation", referring to a concrete system of man and environment which emerges during man's use and experience of the built environment (Ekholm and Wikberg 2008). The concept builds on the idea of "behaviour setting" (Barker 1968), "pattern" (Alexander 1979) and "fabric" (Habraken 2005). A similar concept "sociotop" has been introduced in Ståhle (2008), referring to a unit of place and users where the place has a specific meaning.

We hypothesize that architects design with such socio-technical systems or "situations" in mind. A situation can be described as human activity carried out in an environment with phenomenal properties that support a specific mind-set and experiences during the activity.

In an object-oriented design context, an "architectural object" refers to such situations of people, behaviour, experience and environment, see Fig.1.
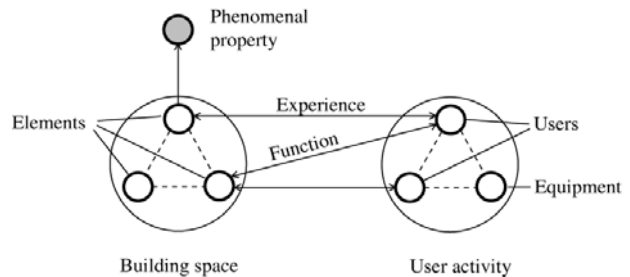

Figure 1. Constituents of an architectural object

2.8 *Architectural objects and product platforms*

In building design the starting point is both ideas of a building type and requirements from a user organization. During brief development a sketch depicting the principle layout and overall characteristics of the building is developed. This sketch defines basic situations in the building. In each situation the activities make use of and experience parts of the building.

Table 2. Identification of architectural objects as a function of technical elements and user organisations in different levels.

Technical modules	Activity/ Design level	Proprietor: Building	Facility management: Apartment	User organisation: Entrance	Bathroom	Kitchen	Living room	Sleeping room
Exterior wall, facade		o	(o)				(o)	(o)	(o)
Interior wall			o	(o)	(o)	(o)	(o)	(o)
Slabs		o	(o)	(o)	(o)	(o)	(o)	(o)
Interior sectional wall		o	(o)	(o)	(o)	(o)	(o)	(o)
Balcony		o	(o)				(o)	
Roof		o						
Foundation		o						

o Active part of design space
(o) Semi-active part, alterations within limits

Architectural object, design modul

In order to identify architectural objects it is necessary to identify which parts of the building that are connected to the activity. The principle for identifying architectural objects is shown in Table 2.

A house building concept may be designed to allow possibilities for variation. In such a case design decisions could be hierarchically related so that decisions in a higher level may allow design decisions in lower levels. In earlier research we have identified such levels that are related to the spatial organisation of the building, e.g. the building as a whole, the apartment, and rooms in the apartment (Wikberg and Ekholm 2008). These levels are coordinated with similar levels of social organisation concerning management and use of the building. Decisions at the highest level concern the building as a whole, e.g. the type and its spatial extension. Within this framework there is a possibility to decide on different floor plan layout and apartment size. Within a determined apartment the spatial layout is to a certain extent flexible based on the distribution of non-loadbearing partitions. There could be architectural objects of interest in all these levels, see Table 2.

Based on technical modules and attributes of an industrialised house-building system, specific architectural objects could be designed to meet both quantitative and qualitative design requirements on different design levels. A system specific pattern of architectural objects in different design levels should respond to the different design requirements.

The hierarchical dependencies of architectural objects could also be illustrated in a tree diagram, showing the design options given by the product platform in a sequential configuration process, see Fig. 2.
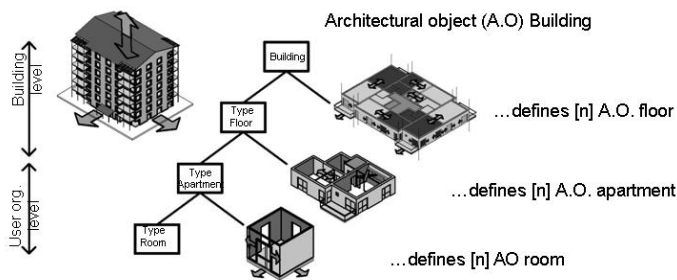

Figure 2. Levels of design decisions.

The illustrated optional sublevel objects may not apply if we would have a house building concept with identical floors, apartments, and rooms which does not allow any design variation. A more elaborate tree diagram of architectural objects could however be used for feasibility studies of an executed architects design or an initial space schematics, towards a specific product platform.

2.9 *Architectural objects and CAD-tools*

Architectural objects to use for design with a technical building platform may be implemented in a CAD-application library together with the functionality of altering it's included parts. The versatility offered by the technical modules and other platform attributes can be reflected in the parametrics of a design tool. For example the architectural objects may have attributes to determine intended building geometry, length, height, number of stories, orientation, relation to open space, position of staircases or access balconies, architectural style, colour etc.

2.10 *Architectural objects and design for variety*

In the example of Veenstra et al. (2006) and their excercise on a Dutch industrialised housing concept, design variation and coupling effects are translated into terms of spatial use. According to them the approach is favourable since it: "improves the communication between the house-building industry and its' customers and improve translating the customers' needs". Their methodology as presented on a specific case has in our interpretation capabilities for application to industrialised housing in general, e.g. our context of industrialised multi-family housing. This is also advocated through the openness towards Open Building. The searched for a tool "for further refine the modularization of the infill components and their interfaces to the chassis (supports)" (ibid) could possibly make use of our theories for architectural objects.

2.11 *Constituting sets of architectural objects*

The same physical components or physical modular objects could as a result of product development be part of different architectural objects. The variety possible to achieve with the technical platform should be reflected in the architectural objects. Limitations may however both be a result of technical shortcomings, and a result of intended restraints due to market profiling, cost reduction, authority requirements etc. A desired balance between commonality and distinctiveness of the product platform should thus be reflected in the flexibility of architectural objects.

The variety criteria follow the types of other modular parts namely as common, standardized or compatible parts (Sanchez and Mahoney 1996, Wolters 2001, Veenstra et al. 2006). The modular interfaces may however not correspond between architectural objects and included technical modules or components, but should be compatible.

3 CASE STUDY

3.1 Introduction

In this case study we want to study the applicability of the concept of architectural object in an analysis of the versatility of a house building platform under development.

The housing concept studied is the result of a design competition announced by the Wood Institute of Southern Sweden. The platform is developed by Tyréns AB, a major Swedish AEC consulting company, for the company Derome, a large actor in timber related business, including house building. The objective is to market an industrialized house-building concept open to a variety of multi-story housing designs. The requirement profile includes facilitating a house building concept of a maximum of eight floors with a mix of apartments open to architectural design and customer requirements. Standards set out by authorities should apply, but the company is interested in focusing on a quality profile rather than a low-cost profile taking life-cycle cost into consideration.

The system should in a first phase be marketed towards clients, architects and proprietors through a design manual and marketing material. An issue for the future is to make the system open to designers through an interactive ICT-supported configurator.

3.1.1 The case objective and methodology

In our case study we will among others examine where design limitations may occur in the house building system developed by Tyréns and direct the need for further technical development of technical modules and components. This is made through

1 Analysing the requirements on the technical platform.
2 Using the results of a QFD related functional requirement (FR) analysis.
3 Presenting a representative pattern of architectural objects.
4 Testing wall related modules against the architectural objects as part of an extended functional relation analysis.
5 Interpreting the output of the matrix, addressing the need for further product development if components or modules are missed out or not up to standard.

3.1.2 Defining the requirements on the technical platform

A number of requirements (and options) on the technical platform (see Tab. 3) were set up by the development team.

Table 3. Requirements on the technical platform. (A=authority, C=client/architect, D=developer).

A1	Accessibility
A2	Statics (Safety)
A3	Environment
	(Energy, emissions etc)
A4	Fire
A5	Accoustics regulations
A6	Daylight rooms
A7	Design (according to local regulations)

C1	Cost efficient living
C2	Large interior / exterior openings possible.
C3	Windows possible close to corners.
C4	Choice of surface finishes possible.
C5	Open to different designs.
C6	Options as to customers choice of appliances.

D1	8 floors maximum
D2	Concrete.stabilizing ground floor
D3	Timber construction 7 floors.
D4	3 or 4 apartments per floor
D5	Mix of apartments, 2, 3 & 4 roomers to demand.
D6	Easy to produce.
D7	Easy to assemble on site.
D8	Cost efficient production
D9	authority
D10	Complying to Swedish standards (accessibility and minimum appliances).

In the company's development work the requirements were used for performing a functional requirement analysis as part of a QFD study, resulting in a guide to which related components and technical modules to develop (see Jensen et al. 2009). In this case study, the requirements are matched against a representative pattern of architectural objects for such a platform, see section 3.2.6.

3.1.3 Performing a Functional Requirements (FR) analysis

Firstly, the production and configuration processes were developed. These work as templates used later in the building project in order to allow for continuous improvements. In the beginning of the development phase of the building system, a multi-skilled development team performed a functional requirement (FR) analysis to identify and systematize the requirements and design parameters for the house building system. This was made as a QFD study, and similar to the first steps carried out in the Design for Variety method.

Table 4. Design parameters effectuated as wall modules

x = Strong Relationship
o = Medium Relationship
(o)= Low Relationship

The process engineers were in charge of developing, as well as updating and managing, the technical and process platform. In the QFD process, the development team translated functional requirements into engineering metrics. The engineering metrics were among others used to determine the properties of different kinds of modular wall elements, such as stabilizing wall elements, see Table 4.

3.1.4 *Presenting a representative pattern of architectural objects*

The building parts of the architectural objects chosen for this study must meet the technical functional requirements as defined in the QFD-process.

The architectural objects were defined for a building type developed in our case study, see Fig 5. It includes 2+2 different apartments for each floor; consisting of either two mirrored 3-rooms apartments, or one 4-rooms apartment and one 2-rooms apartment. Each top or bottom half of the building could include either the first or second alternative of two apartments. The case example is a partly flexible layout offering possibility to respond to changing customer requirements. Our constellation of architectural objects is one of several other possible options.
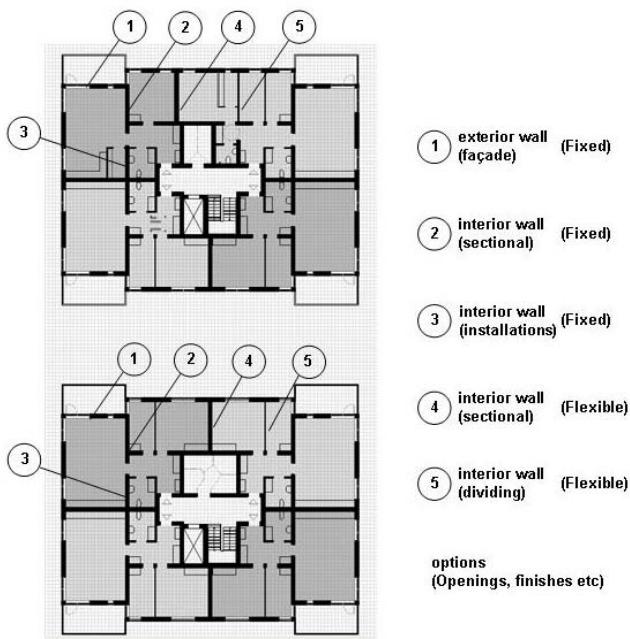

Fig. 5 The reference layout

The architectural objects of this study are divided into different design levels in a hierarchical tree diagram, see Fig. 6, together with the number of instances used. For information, the initial requirements on the platform are also denoted (A1-7,D1-10, C1-5, see 3.2.4). Only superior objects and their served objects are linked by lines, showing major dependencies. Other dependencies or couplings may apply. The same applies to all the rule sets that would be effective in a configurator used for modeling with architectural objects, with parametric design possibilities for all included elements, cou-

plings, regarding limitations concerning to finishes, activities, equipment etc. Much of the data may not even be known in this exemplified early phase of a development cycle.
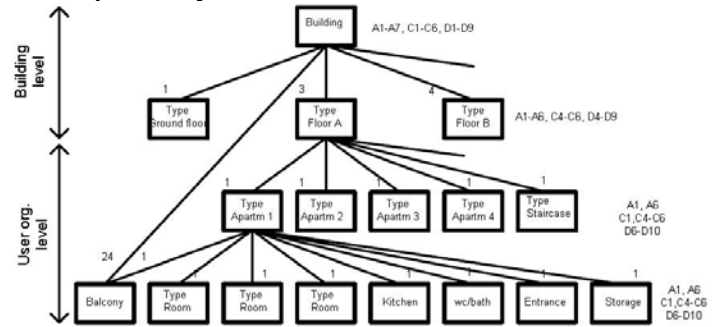

Fig. 6 The relational tree scheme of architectural objects

The illustration of architectural objects as a tree-diagram serves the purpose of assigning the functional requirements to specific architectural objects of different dignity in the hierarchy. It could also in a more elaborate version be used for programming the variety of the platform, as read from the top it illustrates the options available step-by-step according to design levels in a configuration process.

3.1.5 *Testing wall related modules against the architectural objects as part of an extended functional relation analysis*

The wall elements derived from the functional requirement analysis could be cross-checked in a matrix against the architectural objects now serving as 'design objects', see Tab. 5.

		Building space			User organization space				Activity space				
	System; wall related elements	General	Type floor A	Type floor B	General	Apartm type 1	Apartm type 2	Staircase	General	Bathrooms	Kitchens	Bedrooms	Stairs
WALL modules	Exterior stabilizing wall, YV	o	(o)	(o)	x	x	x	x	x	x	x	x	x
	Interior stabilizing wall, SV-A	o	(o)	(o)	x	x	x	x	x	x	x	x	x
	Interior stabilizing wall, SV-B	o	(o)	(o)	x	x	x	x	x	x	x	x	x
	Interior stabilizing wall, SV-C	o	(o)	(o)	x	x	x	x	x	x	x	x	x
	Interior stabilized opening, SV-D	o	(o)	(o)	x	x	x	x	x	x	x	x	x
	Interior Installation/duct wall, SV-E	o	(o)	(o)	x	x	x	x	x	x	x	x	x
	Interior wall, IV1	-	-	-	o	o	o	o	(o)	(o)	(o)	(o)	(o)
	Interior shell wall, ISV	-	-	-	o	o	o	o	(o)	(o)	(o)	(o)	(o)
WALL optionals	Exterior openings	o	o	o	(o)	(o)	(o)	(o)	x	x	x	x	x
	Exterior wall finishes	o	o	o	x	x	x	x	x	x	x	x	x
	Interior openings	-	-	-	o	o	o	o	(o)	(o)	(o)	(o)	(o)
	Interior wall finishes	-	-	-	-	-	-	-	o	o	o	o	o
	Installations, integrated	o	o	o	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)	(o)
	Installations, mounted	-	-	-	o	o	o	o	(o)	(o)	(o)	(o)	(o)
	Wall-hung, equipment	-	-	-	-	-	-	-	o	o	o	o	o

Table 5. Wall elements and dependencies for architectural objects in different levels.

Depending on the respective design level, the wall related elements are more or less active parts of a design decision. The rules of the fields "general" would apply to all sublevels of that design level. This is e.g. the case for load-bearing exterior walls as they must correspond on all floors (building, general design level), which only offers minor design options, denoted (o) on each floor (building, sublevel). This could apply to size of window openings.

However, if no floor alternatives were at hand only one general architectural object would needed on the building level (see also 2.8). Alternatives could still exist within the apartments (user organization level) e.g. regarding internal walls, and in consequence concerning the rooms (activity space designs), making difference between e.g. a bathroom and a sleeping room outfit.

3.1.6 *Addressing the need for further product development*

The matrix in Table 5 could be used for checking whether a design like the one presented in section 3.1.5 is obtainable within the systems building concept. The gray marked area in Table 5 indicates that no active part related to wall modules is present within the sub-level building. This indicates that a design as illustrated in the case, see Fig. 5, is not possible to accomplish without further development of the system. This since a non-load-bearing apartment dividing wall with a fire proofing and acoustic profile is missing in the system. Such a wall would be necessary if flexibility of floor layouts were to be offered.

This could have been more obvious if 'moving of wall possible' had been an explicit requirement. This illustrates the problem of translating initial requirement as 'open to different designs' and '3 or 4 apartments per floor' into engineering metrics as part of a platform development using QFD. Testing modules against a representative matrix of architectural objects could be supportive in an initial phase.

4 ANALYSES

Through the presented methodology and performed case study we have shown the advantages of introducing architectural objects as a measure for testing the intended design capability of a platform.

The results from a company QFD related functional requirement study resulting in the development of a number of wall related modules for the building system proved not to be sufficient. In combination with our methodology the need for further technical development of specific technical modules was recognised.

By completing the initial phase of a QFD study with a cross checking against a scheme of basic architectural objects we see a general way of detecting whether the right modules or options are at hand in a platform for facilitating intended housing designs. Thus customer and other product in-use requirements could be made more transparent in the platform development already in an initial phase. This could save time from executing a QFD until the general layout of the technical modules is determined.

5 CONCLUSIONS AND FUTURE DEVELOPMENT POSSIBILITIES

Previous papers on the subject of architectural objects (Ekholm and Wikberg 2008, Wikberg and Ekholm 2009) have defined and explored the concept of architectural objects. In a case study on systems building with modular volume elements the implicit use of design objects similar to architectural objects was recognized. Making this knowledge an explicit part of configuration methodologies is a key issue in this research project, focusing on architectural design in industrialised house-building. Further studies have shown the relevance of this approach. It may also include studies as to how product development may bridge the gap between different requirement views on a product, as illustrated in this QFD related study. This should be done in order to facilitate architectural qualities and implement lean ideas as concurrent engineering in product development.

Different user organisation levels of a building could correspond to different design levels of a building. Arranged design objects in a tree diagram according to design levels could be a way of expressing the capability of a house-building product platform. Top-down it also illustrates the design objects that a sequential configuration process could make use of.

As concluded in this study a system development team could also make use of a reversed approach as part of an initial QFD process. Representative patterns of architectural objects could be used for testing the capability of technical modules or components at hand.

Through the presented methodology and performed case study we have shown the advantages of introducing architectural objects as a measure for testing an intended design capability of a platform. In product development a technical systems view through the interface of architectural objects could make the system's degree of freedom more transparent. The suggested methodology is establishing dependency relations between the technical platform and customer requirements on the product.

Our methodology could be supportive to the QFD related Design for Variety method presented by Martin & Ichii (2002), and shows parallels to the approach presented by Veenstra et al. (2006).

Future research will primarily focus on the further development of the configuration methodology using architectural objects and the demands for implementation in the processes, but also on the issues concerning modularization and platform development. The general scope of interest is however how to support architectural design in industrialised house-building.

REFERENCES

Akao, Y. 1990. *QFD: Quality Function Deployment - Integrating Customer Requirements into Product Design.* Productivity Press, Portland, Oregon.

Alexander C. 1979. *The Timeless Way of Building.* New York.: Oxford University Press.

Anderson, D.M. 1996. *Agile Product Development for Mass Customization.* McGraw-Hill

Barker, R. 1968. Ecological Pychology. Stanford University Press.

Beim, A., Nielsen, J. & Sánchez Vibæk, K. 2009. *Three ways of assembling a house.* The Royal Danish Academy of Fine Arts, CINARK Copenhagen

Cross, N. 2000. *Engineering Design Methods.* John Wiley & Sons, Ltd

Dikmen I., Birgonul M. T & Kiziltas S. 2004. Strategic use of quality function deployment (QFD) in the construction industry. *Building and environment* 40 (2005) 245-255

Eastman, C., Teicholz, P., Sacks, R., Liston, K. 2008. *BIM Handbook.* Wiley & Sons Inc., Hoboken, New Jersey.

ECTP (2005). *Vision 2030 & Strategic Research Agenda. Focus Area Cities and Buildings.* Version 2. 19 October 2005. European Construction Technology Platform. www.ectp.org.

Egan Sir J. (1998). *Rethinking Construction.* Department of the Environment, Transport and Regions, London: HMSO.

Ekholm A. (1987). The System Man-Building. In: *Problems of Constancy and Change*, vol. 1, 31st Annual Meeting of the International Society for General Systems Research, Budapest.

Ekholm A. & Wikberg F. 2008. Design with architectural objects in industrialised house-building. In *eWork and eBusiness in Architecture, Engineering and Construction*, proceedings of the 7 th ECPPM Sophia Antipolis 2008. CRC Press.

Eldin N. & Hikle V. 2003. Pilot study of Quality Function Deployment in construction projects, *Journal of construction engineering and management*, pp 314-329

Erixon, G. 1998. *Modular Function Deployment – A method for product modularization.* PhD thesis, Royal Institute of Technology, Sweden.

Gann D. (1996). Construction as a manufacturing process? Similarities and differences between industrialized housing and car production in Japan. *Construction Management and Economics* 14, pp 437-450.

Gargione L.A. 1999. Using Quality Function Deployment (QFD) in the design phase of an apartment construction project, *Proceedings IGLC-7*, Berkeley, USA

Habraken N.J. 2005. *Palladio's Children.* MIT Press.

Habraken, N.J. 1998. *The Structure of the Ordinary: Form and Control in the Built Environment.* Cambridge: MIT Press.

Habraken, N.J. 1982. *Transformations of the Site.* Awater Press.

Habraken, J., Boekholt, J., Thyssen, A. & Dinjens, P. 1974. *Variations, the Systematic Design of Supports.* Cambridge: MIT Press.

Hofman, E., Halman, J.I.M. and Ion, R. A. 2006. Variation in Housing Design: Identifying Customer Preferences. *Housing Studies*, Vol. 21, No. 6, 929–943. Taylor & Francis.

Jensen P. & Hamon E. 2009. Product development through lean design and modularization principles. Submitted to IGLC 17, 2009, Taipei.

Jensen P., Olofsson T., Sandberg M., Malmgren L. (2008). Reducing complexity of customized prefabricated buildings through modularization and IT support. CIB-W78 - IT in Construction conference, Chile.

Lessing, J. (2006). *Industrialised House-Building. Concept and Processes.* Lic. Thesis. Division of Design Methodology, department of Construction Sciences, Lund University, Lund Institute of Technology.

Martin, M.V. & Ishii K. 2002. Design for Variety: developing standardized and modularized product platform architectures. *Research in Eng. Design* 13: pg 213-235

McGrath, M. 2001. P*roduct Strategy for High Technology Companies.* McGraw-Hill.

Miles, Robert S., 1997: Ultra fast-track project delivery: 21st century partnering and the role of ADR. *Journal of Management in Engineering*, May-June, pp 45-55.

Morgan J. & Liker J. 2006. *The Toyota Product Development System: Integrating People, Process And Technology.* Productiivity Press.

Noguchi, M. 2003. The effect of the quality-oriented production approach on the delivery of prefabricated homes in Japan. *Journal of Housing and the Built Environment* 18: 353–364. Kluwer Academic Publishers.

Ozaki R. 2002. Customer-focused approaches to innovation in housebuilding, *Construction Management and Economics,* Volume 21 pp 557-564

Robertson, D. & Ulrich, K. 1998. Planning for product platforms. *Sloan Management Review*, Summer 1998:39; pg. 19-31. ABI/INFORM Global

Rönn M. (2001). Three Theories of quality. *Scandinavian Journal of Design History,* vol 11, Rhodos: Copenhagen.

Sanchez, R. & Mahoney, J.T. 1996. Modularity, Flexibility, and Knowledge Management in Product and Organization Design, *Strategic Management Journal*. John Wiley & Sons.

Ståhle A. (2008). *Compact sprawl: Exploring public open space and contradictions in urban density.* PhD Thesis, Stockholm: KTH, Arkitekturskolan

Ulrich, K.T. & Eppinger S.D. 2008, *Product Design and Development*, McGraw-Hill, International edition.

Veenstra, V. S., Halman J. I. M. & Voordijk, J. T. 2006. A methodology for developing product platforms in the specific setting of the housebuilding industry. *Eng. Design* 17:157-173. Springer –Verlag London Ltd.

Wikberg, F. & Ekholm, A. 2009. Architectural objects and systems building. Submitted to CAADfutures 09, Montreal

Wolters, M.J.J. 2001. *The business of modularity and the modularity of business,* PhD thesis, Erasmus University Press, Rotterdam