A PRODUCT DEVELOPMENT APPROACH TO DEVELOPING MODULARIZED AND PARAMETRIC BUILDING SYSTEMS

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ABSTRACT

The context of the Attract project is two cities that needs to be moved in the north of Sweden to allow for further mining exploitation. This paper describes an effort to use product development methods to develop a new low energy building system to be implemented in the transformation of the two cities. The building system should be modularized and have parametric capabilities for flexible and user and configurator based design. The idea is to first state the requirements and then develop the building instead of starting the building development without a clearer picture of the user requirements. Several workshops were held with participants numbering up to around 30 people who represented users, the municipalities, construction companies and the mining company. Some workshops contained the following phases: customer requirements, product specification and initial concept generation. Others focused customer requirement where people involved in the building project could express their needs, requirements and issues first individually, then discuss them between two or three people and finally present them for all people in the workshop.

The approach stimulated the participants to express needs, thoughts, and questions that helped specifying the limits, opportunities and challenges of the project. The multiphase workshops iterated between the different phases in order to detail the aim of the project and keeping up the momentum. The multiphase workshop enabled the participants to approach the project from different viewpoints, whereas the need and requirements themed workshops were shorter and therefore had a more focused agenda. From this research product development methods are argued to stimulate user-based development of modularized and parametric buildings.

Keywords: building development, product development methods, configurator development, modularization, cold climate

1. INTRODUCTION

Some of the most important decisions are taken during early construction design as these decisions directly impact manufacturability or buildability of the construction. These decisions depend extensively on design team experience, an experience that not always is available as experience people doing a good job tends to get promoted and change positions or project types. Configurators can show the design change impact on e.g. cost, equipment availability, staff capabilities and buildability and also help designers reuse successful solutions from earlier work instead of reinventing the wheel for every project. With configurators, several design alternatives can be generated instead of manually just creating one alternative, which often is the case in construction. Here configurators are referred to as software applications that automate part of the CAD (computer aided design) work, usually time demanding routine work. An issue is that many construction companies are not aware of the potential of automated CAD. Within the manufacturing industry a lot of work has been done to develop configurators see e.g. Chapman and Pinfold (1999) and La Rocca and van Tooren (2012). Also the construction industry has started to show configurator related research e.g. Jensen et al. (2012) and Cheng et al. (2008). To help the construction industry to see the potential of automated CAD a methodology that guide configurator development could be of interest. Within the manufacturing research field methodologies exist e.g. MOKA (Methodology for Knowledge Based Engineering Applications), and (Hvam et al., 2008) but within building construction such comprehensive methodologies are to the best of the authors' knowledge missing. These methods cannot directly be adopted because of the differences between building and manufacturing e.g. lower level of digitalization, project-based instead of process based organization (Koskela, 1992) and loosely coupled supply chains (Dubois and Gadde, 2002).

The manufacturing industry uses product development (PD) processes to go from idea to produced product. The overarching format of PD-processes form an interesting starting point for the future creation of a construction configurator methodology rather than starting to modify the already detailed MOKA methodology. Therefore a PD approach is chosen to be explored during the development of the modularized and parametric building system. This paper presents the initial steps of the exploration of using a PD-approach to create a new modularized low energy building system and a supporting configurator.

The research is done as an explorative case study within the Attract Project (Attract). The Attract project includes the development and production of a new low energy building for the sub-arctic climate of northern Sweden.

2. RELATED WORK

2.1 Product development

According to Ulrich and Eppinger, (2004), p. 12: "A product development process is the sequence of steps or activities which an enterprise employs to conceive design and commercialize a product."

A product development process is depicted in Figure 1 where the important manufacturing considerations are outlined as feedback arrows.

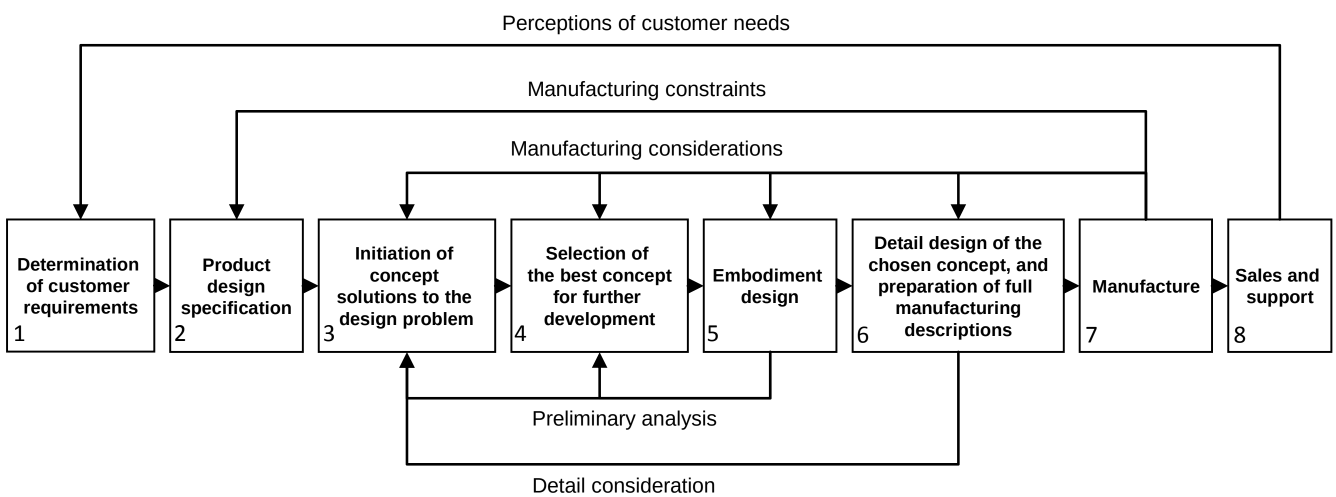

Figure 1: A product development process, based on (Wright, 1998)

Determination of customer requirements (phase 1) includes doing market research. Interviewing and observing former and possible customers to find out their behavior and needs is part of this. Also there are customers on different levels. For building customer can be habitants, real estate owners, municipalities etc. There are also requirements that can be found in the societal regulations. *Product design specification* includes translating the customer requirements into a number of statements that define the design problem. *Initiation of concept solutions to the design problem* is the creative phase of generating design ideas through for example brainstorming. During phase 4 one or more ideas are selected for further development. This can be done using decision matrices for instance. *Embodiment design* contains activities to create the shape of the product. Embodiment design can also be counted as part of early design when design decisions have an impact on cost.

Phase 6 includes development of the design details and development or planning for the manufacturing. In the last two phases the design is produced and then sold to the customer and support (e.g. maintenance) can be provided.

2.2 Construction configurators and support tools

Knowledge-based systems have been around since the 80's in the construction industry (Gilmore, 1989). Olofsson et al. state that together with organizational changes computers can enable enhancements of the industrialised house-building industry (2004). Below a number of configurators and support tools in construction are briefly described in terms of how they were developed.

There are a number of configurators developed, e.g. (Jensen et al. 2012, Sandberg et al., 2008). Configurators are often rule-based parametric CAD-models of the building system that enable design by reuse of existing modifiable solutions. Jensen et al. have developed a floor-slab application and argue that manufacturing CAD software can be used for design automation within the construction industry (2012). The approach (rather than method) used for the application development is described as: Firstly a multi-skilled engineering team was assembled that together with a building manufacturer defined constraints and requirements for the building system. Secondly a modular system was developed based on the constraints and requirements. Design rules was defined and implemented into a floor-slab application. Lastly the application was evaluated by undergraduate students.

Sandberg et al. presented a support tool for stair and structural floor design and used a development approach that started with choosing a design scenario and tool functionality, acquiring knowledge, formalizing the knowledge into rules and implementing the rules into an application, (2008).

Decision support systems for method selection for concrete building design have been reported by Chen et al. (2010). The support system was developed according to the following approach: Firstly interviews with clients/developers, engineers, contractors and precasters were done to collect data about how they make decisions. Secondly this data was verified and then it was formalized into relationships that could be used to select method for concrete building design.

Artificial intelligence has also used to develop decision support in construction, e.g. Kaklauskas who presented an application for choice of windows (2007). Firstly other decision support systems were analysed and guided the development of the presented decision support system that consists of a database, database management system, model-base, and model-base management system and user interface. The system was then tested for usefulness.

Cheng et al. report on a tool for decision-making and assessment of high-rise building systems (2008). Firstly the implicit decision-making procedure was documented and therefore made more explicit. Secondly the procedure was assessed and verified.

Attia et al. present a support tool for early design of zero-energy buildings (2012). First barriers, requirements and expectations were identified then a tool was developed to meet these. The tool was then tested twice for validity and usability respectively.

Lam et al. presents an internet-based performance simulation tool for early building design, (2004). The tool was developed using a bottom-up approach.

2.3 Research motivation

The configurator development methodology is seldom in focus in previous construction research why this field needs to be explored further. Most construction configurator research describe the resulting configurator in detail and just explain how they developed the configurator briefly. Therefore there is still room for exploring alternative configurator development approaches. The majority also focus the development of configurators for a mature or at least already developed design building system. Therefore it is also of interest to explore the pros and cons of developing a new building system and make this system suitable for a configurator.

3. METHOD

3.1 Case study

Attract (Attractive and Sustainable Cities in Cold Climate) is carried out by a strong research environment in cooperation with companies and municipalities. Today, 18 partners are engaged in the project consortia. The partners contribute with necessary knowledge and skills to jointly generate innovative products (goods and services) for attractive living in cold climate, for 1) attractive almost zero energy homes in cold climate, 2) attractive outdoor environments in cold climate, 3) sustainable and integrated energy supply and urban water systems in cold climate, and 4) attractive and sustainable urban development in cold climate. The consortia will address a number of needs related to attractive living in cold climate, namely: to produce attractive almost zero energy homes that fulfill upcoming EU-regulations to use a combination of sustainable energy supply systems (sun, wind, distance heating, etc.) to heat the buildings, despite subarctic (cold) climate to develop and integrate new sustainable technologies with existing systems to design an attractive outdoor environment that sustainably can handle snow, melt- and rainwater to design the outdoor environment to encourage neighborhood spirit despite cold climate.

Within the work package *attractive almost zero energy homes* a building system is being developed by LTU, Tyréns and Sweco. The goal is to use this building system to produce at least one complete house. During the development of building permit drawings which should be finished by September 2014, a configurator will be programmed that will support building design. The configurator development will give excellent input to the development of the PD-approach since the authors' university is one of the intellectual property owners of this building system.

3.2 Workshops

Several workshops were held with different participators and with different contents. The customer is seen as the habitant of the building.

Table 1: Workshop overview (X – primary focus, x – secondary focus).

	Length (hours)	Participants	Determination of customer requirements	Product design specification	Initiation of concept solutions to the design problem
Workshop 1	5	Two consultancy firms and the authors: 9 people	x	X	X
Workshop 2	1,5	Users, municipality, consultancy firm, building entrepreneurs, mining company, authors: ~30 people	X		x
Workshop 3	5	Two consultancy firms and the lead author: 7 people		x	X

3.3 Structural timbre system as starting point

Although the building system being developed from scratch parts from an already designed structural timbre system will be used. The existing system is modularized and parametric. Updates are needed for new requirements regarding energy, flexibility and subarctic climate. The system has bearing inner walls, timbre frames and steel frames, stabilizing wall elements and outer wall elements. The modularization is built from a grid with 150 mm between the lines. The configurator has several views for customers, engineers and production staff respectively. Figure 2 shows a breakdown from project level down to wall element. For more details see (Träplattformen).

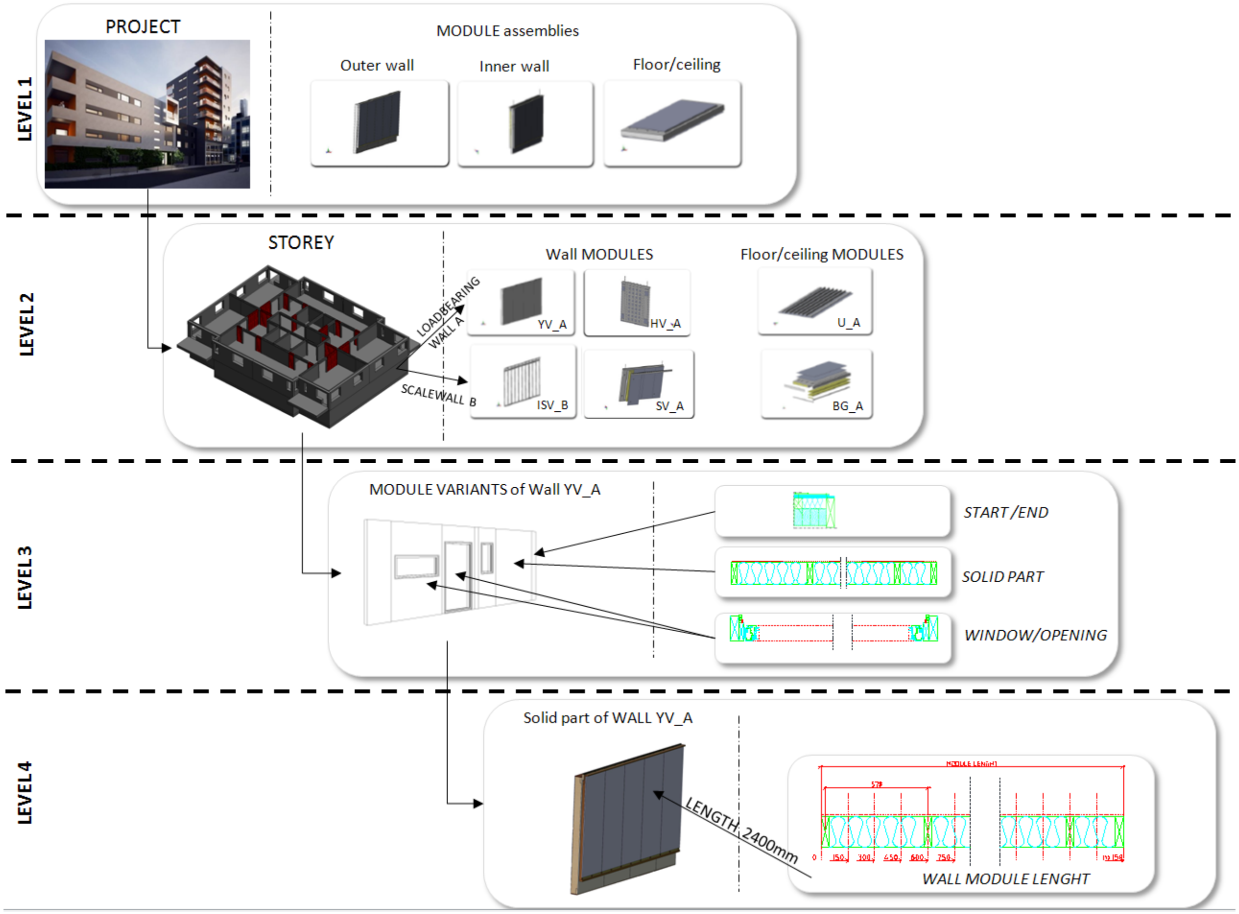

Figure 2: Excerpt from the starting point structural timbre system

4. RESULTS

4.1 Determination of customer requirements

The first workshop only touched on needs and the outcome was:

- Storage space for belongings
- Able to drive a snowmobile
- Additional housing for rent
- Attractive appearance
- Ample lighting
- Location with nice view
- Efficient use of space
- Different solution for condominium and tenancy respectively
- Area to socialize and invite people to
- Sauna
- Open plan
- Proximity to transport

The majority of the customer requirements came from workshop 2. After all participants have written down requirements on post-it notes started a lively discussion between the neighbor's table when five notes should be selected. Some chose the notes in pairs while others chose in groups of more people. The groups then presented their notes while putting them on the board and then the categories emerged. Some notes fit under several categories but was still chosen to be under a certain category since the categories overlap. When all the notes were set, the idea that a weighting of the categories would be done, but the number of notes per category represented a weighting in itself. The following table shows the number of notes per category.

Table 2: Number of notes per category

Category	**Number of notes**
Comfort	24
Energy	12
Flexibility	9
Economy	7
Integration of indoor and outdoor environment	5
Outdoor environment	5
Operation and maintenance	4
Appearance	3
Building technology	3
Safety	1
Premises	1

As the table shows, the comfort, energy and flexibility categories had most notes while building technology, safety and premises had least.

4.2 Product design specification

After discussions during workshop 1, the following result was reached. Uniquely designed apartment blocks with great flexibility, energy efficiency and long spans with the potential to premises should be developed. Here apartment buildings are focused but houses cannot be seen as entirely excluded. Flexibility means that the building system can be used to create many different variations of apartment buildings and specific house models (catalogue houses) are not in focus. The design concept is partly parametric meaning that the fundamental parts of the house (that will look similar to all house variations) will be parametric. Energy efficiency is in the nature of the project as it deals with low-energy (50% of BBR – Swedish regulation), but more specifically, heat exchange for example district heating return should be used. With long spans, longer spans than timbre structures handle in the current situation are referred to. Therefore, timbre, steel and concrete are allowed materials. As for the economy, an approximation is that the cost of houses built with this building system should cost less than a site-built house but more than prefabricated volume constructions. Design is done for the subarctic climate in the first place, while other factors such as moisture is dimensioned by other climate zones such as those in southern Sweden. Angles between the walls should be able to be different than 90 degrees to allow for more architectural freedom. Then a relationship between building envelope, floor area and window area is included as a parameter as the basis for the architectural design. For production, the idea is to encourage local companies in the mining areas as far as possible but, for example, timber elements probably have to be manufactured somewhere else.

Workshop 3 also gave the following output: Aim for level gold according to the Swedish Green Building Council certification programme.

4.3 Initiation of concept solutions to the design problem

The building system has 4 to 8 story's. Timbre, steel and concrete will be used as well as other materials. A steel frame and a concrete module to where the elevator shafts, bathroom and kitchen attached should be used. The facade can be flexibly changed from house to house to fit in with the surroundings therefore being both attractive and energy-efficient (making just energy-efficient homes with less care of attractiveness is easier since thicker walls and fewer windows reduce energy consumption). The best solutions from an open (anyone can use it) structural timbre system developed by one of the participating consultancy firms should be used, see Figure 1.

5. DISCUSSION AND CONCLUSION

The new building system is based on a modularized structural timbre system. The building system will firstly be defined detailed enough before starting to develop the modules. The goal is to create CAD-models that are parametric, e.g. Revit Families and/or using manufacturing CAD-systems such as SolidWorks with more parametric capabilities.

Several open questions came up during the work. One is regarding the level of modularization and parameterization. One alternative here is to keep the levels of the starting structural timbre system, see Figure 1. Another question is how to manage the thermal radiation. This can be done by placing the windows deeper into the walls. A third question was what level of prefabrication to use. One idea is to have a prefabricated steel structure with built in fastening devices. On this steel structure prefabricated curtain walls could be attached. Questions regarding economy and news value also were posed. Economy can be enhanced with increased number stories but this need to be balanced with customer requirements and with the building site. Regarding the news value two alternative building systems were benchmarked: one strongly standardized for up to 4 stories and one in timbre volumes. It is argued that one news values is increased flexibility and more focus on attractive appearance besides enabling low energy efficiency for subarctic climates.

Regarding the used PD-approach the first four phases in Figure 1 have now briefly been visited. Even though the phases are sequential the phased have been visited several times during iterations. The questions regarding modularization and parameterization has started to appear and will be treated more and more as the building system takes shape. So far the PD-approach is seen useful, although it has been used on an overarching level rather inspiring and guiding the research than governing the research. The process also need to be used during several development projects before it can be fully evaluated. In the future work we plan to visit the rest of the phases in Figure 1 as well as make modifications that make the process more construction and configurator development friendly.

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