Customization of buildings using configuration systems - a study of conditions and opportunities in the Swedish timber house manufacturing industry

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Customization of buildings using configuration systems

A study of conditions and opportunities in the Swedish timber house manufacturing industry

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Licentiate Thesis

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“They always say that time changes things, but you actually have to change them yourself.”

- Andy Warhol

Preface

We jointly create the environment we work and live in, a fact that I have increasingly come to realize. I believe that Eugène Ionesco was right for several reasons when he said "*It is not the answer that enlightens, but the question*" - a statement especially true for researchers, which I believe must be driven by their curiosity. I think that I have been on a quest for answers during the course of this project. Now that I am hopefully enlightened, I might provide you with some insight.

I would like to thank professor Sven Thelandersson for being my supervisor as well as mentor throughout this journey. I would also extend my gratitude to my former colleagues at Tyréns, especially Stefan Persson and Patrik Jensen – without our cooperation and support I would never have come this far. Thanks also to Thomas Olofsson and Helena Johnsson at LTU for your support during this project, to the division of structural engineering at LTH for always contributing to a positive work environment. Thanks to all Ph.D. students in Lean Wood Engineering for all fun gatherings. Thanks to Ronny Andersson and Miklos Molnar for your support and advice.

A special thanks to Tyréns for financing and to Lean Wood Engineering for creating an excellent research environment.

And finally, to Jessica and my family who has to put up with me not always taking the straightest, most appealing path towards the goal.

LINUS MALMGREN
Lund, February 2010

Sammanfattning

Projektets syfte har varit att studera trähusindustrin och ge riktlinjer till de trähustillverkare som har tankar kring att effektivisera verksamheten genom att införa produktmodeller och i förlängningen använda konfiguration. Slutsatserna i denna rapport baseras på en rad fallstudier bland trähustillverkare, vilka utgör en grund för analysen och de rekommendationer som ges i rapporten.

Den svenska trähusindustrin har en mångårig erfarenhet av att tillverka hus på fabrik. Under senare år har dock byggbranschen fått kritik för problem med kvalitet och produktivitet, problem som även gäller för trähusindustrin. Under byggbranschens uppgång det senaste årtiondet har inte IT-investeringarna i trähusbranschen riktigt hållit samma nivå som övriga investeringar. Av denna anledning har därför många företag idag ålderstigna IT-miljöer, detta är troligtvis en bidragande orsak till dagens situation. På flera sätt liknar trähustillverkarna de traditionella platsbyggda projekten i sin uppbyggnad, speciellt gällande hur man hanterar produktdokumentation och IT. Med tanke på de olika förutsättningarna och det faktum att trähusindustrin har större möjligheter att tillgodogöra sig influenser från andra industrier, medför att branschen har en intressant möjlighet att utveckla verksamheten.

Resultaten från fallstudierna visar att trähusindustrin har en potential i att bättre integrera sina processer, användandet av IT samt hur man hanterar produktdokumentation. Hur trähustillverkare ser sin egen verksamhet påverkar också man hanterar frågor kring ovanstående områden, vilket i slutändan också påverkar hur väl man kan utnyttja konfiguration. Oavsett om de ser sig själva som ett byggföretag, en ingenjörsfirma eller en tillverkningsindustri kommer bilden av hur man ser sig själv att påverka många aspekter av hur man driver verksamheten.

Slutsatserna från projektet visar på att det finns en potential för trähusindustrin i att effektivisera och standardisera produktdokumentation för att underlätta konfiguration samt i att förbättra de processer som inkluderar produktspecifikation. Företag bör uppmärksamma tre områden som del i denna förändring: processer, IT och produktdokumentation. Med ett gemensamt fokus på dessa områden har företag en möjlighet att öka sin konkurrenskraft genom effektivare processer och standardiserade produktfamiljer. Det finns naturligtvis också risker med att införa nya IT-system och i att förändra processer. Företag måste själva väga de risker som finns och hur de står i proportion mot de fördelar som finns att vinna. Risker som bör tas med i en analys är t.ex. förändringar i marknaden, kostnader och att kvantifiera fördelar med konfiguration.

Rapporten ger ett antal råd till trähusindustrin som kan vara nyttiga att överväga för de företag som vill gå vidare med produktmodellering och konfiguration. Exempelvis rekommenderas att företag undersöker hur man skall definiera roller och ansvar för IT-chef respektive konstruktions/teknikchef, att undersöka hur IT-strategin bäst

levererar värde till verksamheten samt att utreda möjligheten att införa en produktutvecklingsprocess.

Sökord: industriellt byggande, informationshantering, it, produktmodellering, produktspecifikation, trähus

Summary

The aim of this project has been to study timber house manufacturers and provide guidance to those who aim to increase efficiency through the adaption of product modeling and eventually configuration. The findings in this report are based on a series of case studies within the abovementioned industry, which serves as a basis for the analysis and recommendations given.

The Swedish timber house manufacturing industry has a long tradition of producing houses in factories. In recent years, however, the construction industry has received criticisms for issues with quality and productivity, problems that is also valid for the timber house manufacturers. During the upswing in the past decade, IT investments in the industry have not kept the same pace as other investments. For this reason IT environments are currently growing out of date, which is one reason contributing to today's problems. In many ways the timber house manufacturers resembles traditional on-site construction, especially in how they use IT and product documentation. Given the different conditions in the industries and the fact that timber house manufacturers can assimilate influences from other manufacturing industries, this presents an interesting opportunity to pursue for the industry.

The results from the case studies show that companies have a potential to better integrate processes, use IT and manage product documentation. How timber house manufacturers view themselves also affects how they treat questions regarding abovementioned areas, which ultimately also affects how well they will be able to use configuration. Whether they see themselves as a construction company, an engineering firm or a manufacturing industry will have an effect on many aspects of how to run the business.

The findings show that the timber house manufacturing companies has a potential in streamlining and standardizing product documentation to facilitate configuration and improving the product specification process. Companies should address three areas as a part of the change: processes, IT and product documentation. When considering these three areas together, companies have an opportunity to increase their competitiveness through more efficient processes and standardized product families. Clearly there are risks associated with introducing new IT systems and changing processes. Companies need to consider the risks and potential benefits with pursuing this path. Risks that should be included in an evaluation are for example; changes in the market, costs and quantifiable benefits from using configuration.

The report provides a number of advices to the timber house manufacturers that might be useful to consider for companies that wishes to go forward with product modeling and configuration. For example, it is recommended that companies investigate how to define the roles and responsibilities of the Chief Information Officer and Chief

Technology Officer, explore how the IT-strategy best delivers value to the business and consider to introduce a product development process.

Keywords: industrialized construction, information management, it, product customization, product modeling, timber buildings

Contents

Appended Papers

PAPER I ***ICT support for industrial production of houses – the Swedish case***
Helena Johnsson
Linus Malmgren
Stefan Persson
CIB W78 Maribor 2007 Conference Proceedings

PAPER II ***Information management in industrial housing design and manufacture***
Stefan Persson
Linus Malmgren
Helena Johnsson
Journal of Information Technology in Construction 2009, Vol. 14

PAPER III ***Product modeling of configurable building systems***
Linus Malmgren
Patrik Jensen
Thomas Olofsson
Submitted in December 2009 to Journal of Information Technology in Construction.

Abbreviations

AEC	Architectural, Engineering and Construction
BIM	Building Information Model/Modeling
CAD	Computer Aided Design
CIO	Chief Information Officer
CTO	Chief Technology Officer
GPA	General Procurement Agreement
IS	Information System
IT	Information Technology
KBE	Knowledge Based Engineering
MFD	Modular Function Deployment
QFD	Quality Function Deployment

1 Introduction

1.1 Background and problem statement

The construction industry has experienced an upswing during the larger part of the latest decade; unfortunately IT investments have not followed at the same pace and many systems in the timber house manufacturing industry originate from implementations done in the 90ies. Issues with IT in general and information management may risk impeding the future growth of the timber house manufacturing industry. There might not be a pressing need for a revolution, but they must certainly follow the path of evolution, otherwise the industry may find it challenging to stay profitable going forward. Currently there is also a lack of interoperability in the construction industry, as an example the annual costs of inadequate interoperability in the US capital facilities sector alone, are estimated to 15.8 billion USD, Gallaher et al (2004). Therefore IT, which can serve as a platform for integration must be seen as a significant part of the changes to come in the industry. During 2009, the timber house manufacturing industry in Sweden have experienced a substantial dip, in January turnover went down 34 percent to 2 933 MSEK compared to 2008, TMF (2010). The development of all started detached houses projects in Sweden between 1990-2009 is shown in Figure 1.

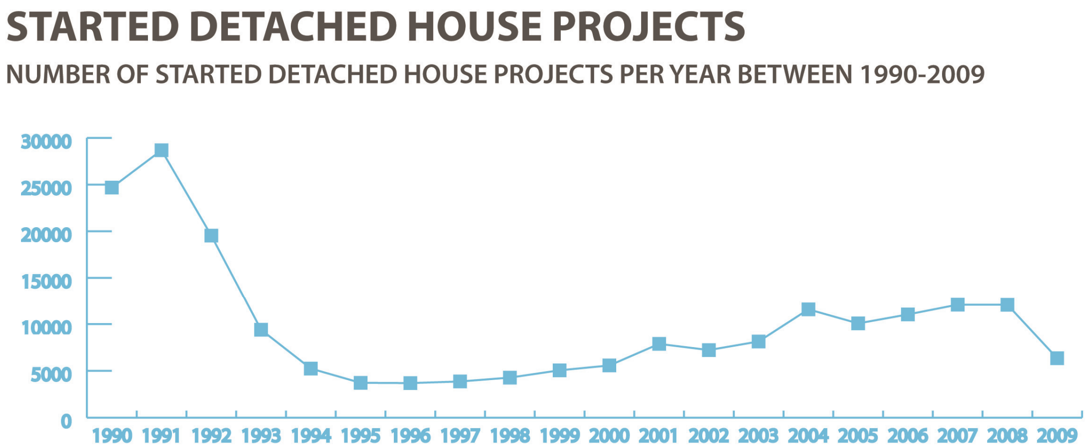

Figure 1 Timber house manufacturing statistics. SCB (2009).

Many have identified industrialized construction as more than rethinking the manufacturing process, for example Lessing (2006). Current industrialization initiatives in construction have been influenced by automotive, shipbuilding and other more experienced industries, Björnfot (2006) Robertsson and Ekholm (2006), and industrialization is by many stakeholders in the construction industry seen as the most feasible way to increase effectiveness, Ekholm and Molnár (2009). In the manufacturing industry, IT has widely contributed to the industry's efficiency development, Ekholm and Molnár (2009), which also drives industrialization. Industrialization has been one of the major drivers for the construction industry when trying to raise efficiency by using more elaborate IT solutions. Despite the similarities, different industries operate on different markets and on different conditions that makes it nearly impossible to use copy and paste methodology when trying to industrialize the construction industry. For the timber house manufacturing industries, that jointly delivered 2300 living spaces on the domestic market during 2009, TMF (2010), it will hardly prove to be a cost efficient solution to adapt large-scale lean programs, automated production or similar solutions with their current turnover and resources available.

Starting with the report "Skärpning gubbar", Byggkommissionen (2002) released in 2002 and continuing with "Sega gubbar?", Gustavsson and Rupprecht Hjort (2009), it has become more and more obvious that the Swedish construction industry has to face its issues; quality, cost and reliability. Industrialization has been seen as one way of dealing with the issues at hand and several examples exist. Although not all examples have proved successful on short term, the industry is experiencing change and is adapting to the new market conditions. BIM[1] has been another way of dealing with quality and cost that has gained momentum, but has not yet been widely adopted by practitioners, Eastman et al. (2008) Linderoth (2010).

There is also a trend to transfer methods such as lean production to the construction industry, Koskela (1992). Coming from a state where the construction industry has experimented with different methodologies it has become more and more evident that they have to develop their own path instead of applying other manufacturing industries business logic. The Swedish industrialized construction sector has in the last years, up until 2008, had a strong development and has seen a strong new presence of tools and methods aimed at increasing productivity, mainly contributed by the research community. Lean, agile, configuration, product modeling etc. are concepts new to the Swedish construction sector that historically has not been an early adopter of new technology. But the strong focus of the research community towards industrialization of the construction sector have to some extent inspired.

Gerth (2008) describes how the business model of NCC Komplett was built up. This was a vision of industrialized construction sprung from manufacturing industries including a highly automated factory where products were finalized on several production lines according to lean principles and on-site work was minimized, see Figure 2. However, after spending 1 000 MSEK (100M EUR), NCC decided to close down the factory when it did not deliver as promised, NCC (2007). In spite of the

[1] BIM – Building Information Modeling

discontinuation of NCC Komplett, this and other initiatives have learned the industry how they can (or how they cannot) approach industrialization.

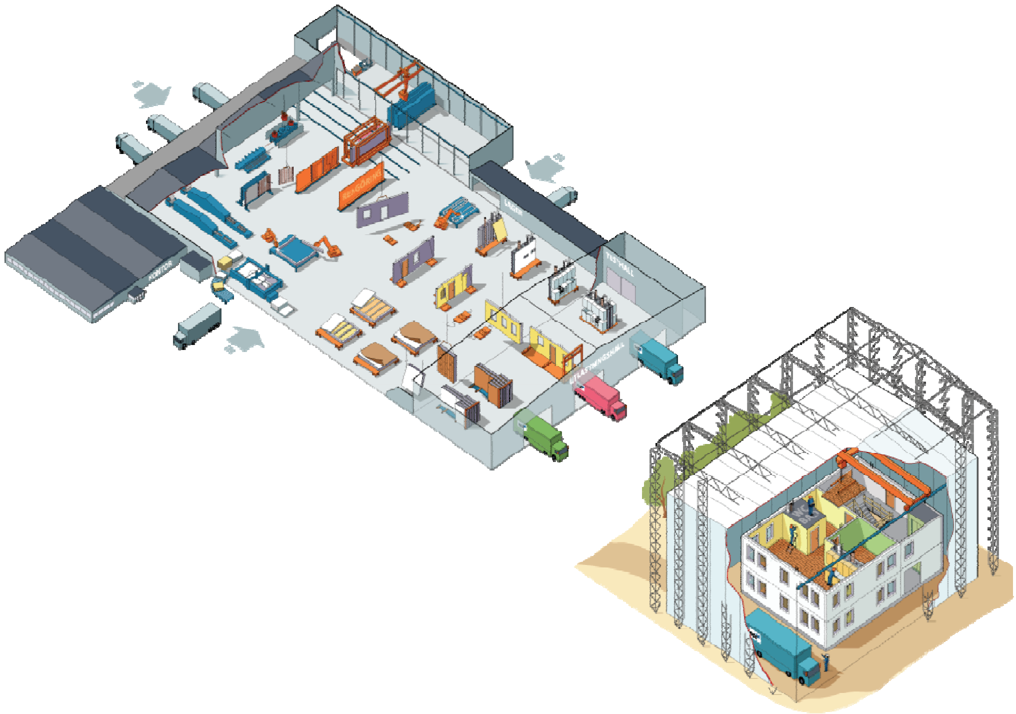

Figure 2 NCC Komplett revolutionary production process and on-site assembly. Gerth (2008)

Generally, the construction industry is very good at capturing needs of their customers, but instead lacks in process governance for product development and production, which leads to recurring quality issues and low productivity, Ekholm and Molnár (2009). According to Winch (2003) on-site production is what separates the construction industry from other industries; which would indicate that there is little difference between industrialized construction and other industries, given that on-site work is minimized. Other studies have concluded that the construction industry has its own characteristics that must be accounted for; the most prominent may be its project focus, Lessing (2006). It is also important to understand the structure of the market, which is unique for each industry and must have an effect on the production system.

As the timber house manufacturers is somewhere in between manufacturing and construction, they are struggling to form an overall IT strategy. Historically they have used IT developed for construction that has consequently influenced the organization and contributed to the continuation of a project focused business strategy. To raise efficiency, they need to adopt more of the IT strategies from manufacturing industries that operate differently and more alike themselves. Based on the situation described in the appended papers, we currently see a somewhat fragmented IT environment with room for improvements or even a paradigm shift. Clearly, neither IT strategies of traditional construction fit nor can they directly implement strategies from other manufacturing industries. This is an industry collective issue and as well an issue that needs to be addressed by each company alone – one unified solution that fits all without tweaking and tuning will not come within a foreseeable future and companies need to act by them selves. Actions have been seen in some companies.

According to Ekholm and Molnár (2009) manufacturers of products and systems (for example windows and precast concrete elements) already work according to industrial principles with a clear separation between product development and individual building projects – process focus is considered one of the key elements when looking at industrialization, which would indicate that this sector of the industry have come further in terms of industrialization. Not only a clear separation between processes distinguishes companies that are working according to industrialized principals. Also the separation between product development and specification process will tell how companies are approaching industrialization, see Figure 3. The timber house manufacturing industry has the ability to be the next segment of the construction industry to adapt principals of mass customization, which could push them down the scale in Figure 3. The potential is evidently there and as they own larger parts of the process, the most obvious piece of the puzzle that is missing is knowledge of industrial processes, product modularization and IT strategy, Persson et al (2009). If more automated production is one of the forward-looking goals, one of the first steps is to have a distinct product documentation as a base for an information strategy, Ford et al (1995), which must be a starting point for most of the companies in the sector.

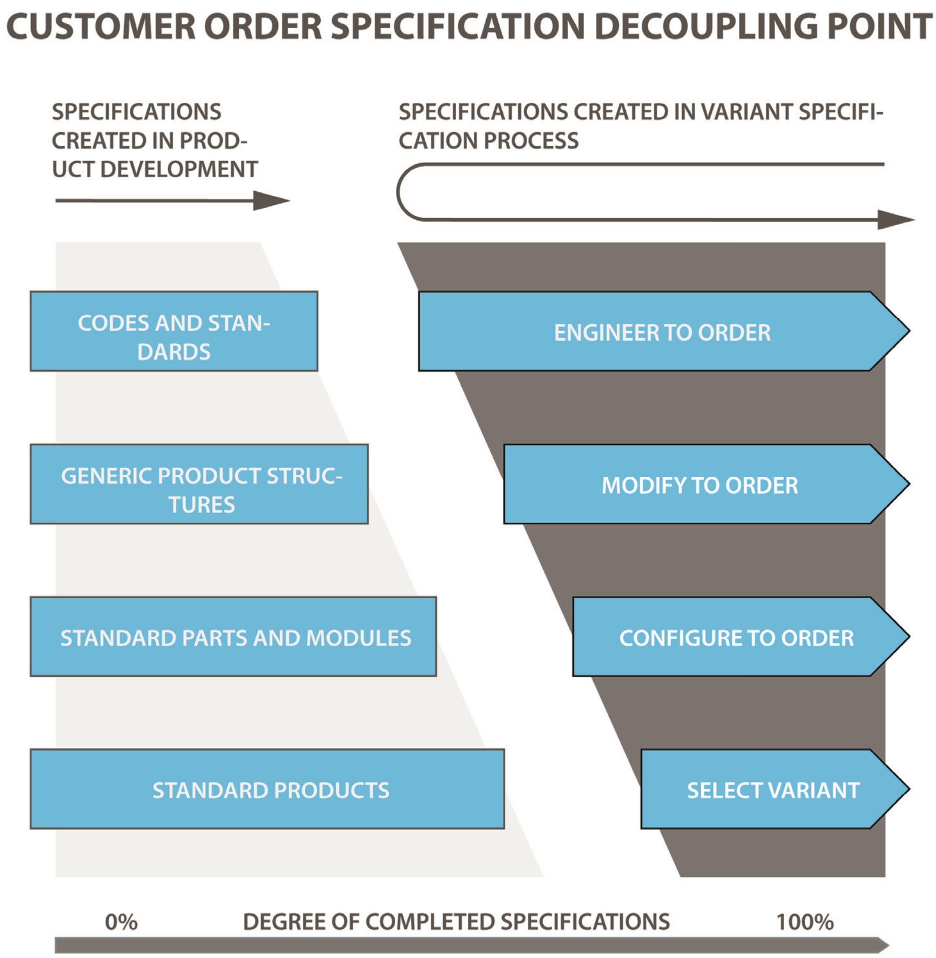

Figure 3 Types of specification processes. Adapted from Hansen (2003).

Companies in the timber house manufacturing sector are generally small to medium sized and do not have any financial capital or knowledge to invest heavily in IT, they therefore to a larger extent have to rely on standard IT systems and solutions. This requires an understanding of available systems and how to make the most of them with little customization. Unfortunately, the IT systems developed for the construction sector are not made to fit the industrialized construction process, while the tools developed for the manufacturing industry lack support for structural design and detailing, Johnsson et al (2006). Consequently companies struggle with how to identify themselves and how to form a feasible IT strategy. In Simpson (2004) there is a list of a several configuration systems and examples, but none for construction.

Modularity has gone from the meaning of geometry and proportions to contain a meaning of functionality. Today mass customization is making its entry into construction through modularized product platforms. This has the potential to take construction companies from building a concept in every project to the use of repetitive manufacturing processes. Mass customization has a long history and is closely connected to modularity and product platforms. Through the use of influences from mass customization, timber house manufacturers have the potential to leverage product platforms and configuration to increase their competitiveness through a more efficient product utilization and higher quality. Milestones on this journey are product modeling and an appropriate IT strategy, which has been the focus of this project. This leads up to the problem statement:

> *How can companies embrace a product platform strategy that leverages the benefits of configuration? What is the potential and what steps do they need to take in order to start their journey?*

Reasons for choosing to study the timber house manufacturing industry are manifold. It has a long and interesting history in Sweden; as timber is natural resource in Sweden it has always been associated with house building traditions. Industrialized timber house manufacturing has evolved from saw milling when companies have tried to increase the level of value added to their products. Partially because of the history, products have been the center of attention rather than industrialization and focus on efficient manufacturing. In the late 80'ies and early 90'ies there was an upswing in the Swedish real estate market and while making money, many timber house manufacturers took the opportunity to invest in new IT systems, mainly CAD[2]. Since then there has been little attention to the IT systems, which are getting more and more outdated. If companies do not want to fall behind on a market that is getting tougher, they need to update their IT strategies to stay competitive, which may also mean a change in business model as well as embracing new paradigms such as mass customization. Although this may seem as an overwhelming task, this report aims to give some direction to the business on where and how to start.

This project has touched on somewhat different fields of research, which in my point of view makes it more interesting, but also more challenging. There is a need to help the sector evolve into an industry that is ready to meet the competition of the construction sector now and in the future.

1.2 Objective

The high level goal of the project has been to assist the timber frame industry to find a way forward to leverage the benefits of IT in similar ways that other manufacturing industries have. Focus has not been to develop and implement a new system, but to point out the way forward – every company must then drive their own transformation and set goals for how they want to use IT and technology strategy.

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[2] CAD – Computer Aided Drawing

This report is based on a project performed in cooperation with the Swedish timber house manufacturing industry and has focused on the prerequisites for efficient IT support for design and manufacturing. In detail, focus has been on the prerequisites for product configuration, specifically the stages of product modeling and the processes in which the configuration is performed. Ekholm and Molnár (2009) states that Swedish R&D programs have failed to present results that can be directly implemented in the industry, one reason for this could be the lack of stakeholder analysis. By including companies this project aims to address as many stakeholder issues as possible.

The aim of this project has from start been to understand and quantify the opportunities that configuration in construction can provide and how the companies in the timber house manufacturing industry can leverage these opportunities. During the course of time, the aim has evolved to include how IT, product modeling and processes are connected and how they must link to each other.

1.3 Research questions

Based on the problem statement, the overall research question has been formulated as a chain of questions leading up to some advice for the industry:

1. *How do timber house manufactures need to develop to adopt configuration systems?*
2. *What effect on the internal systems will a change of the specification process have?*
3. *Is configuration the right solution to pursue for the timber house manufacturing industry?*
4. *How can companies proceed?*

1.4 Limitations

This research is mainly built on case studies performed in the Swedish timber house construction industry during 2006-2008. The studies have been focused on detached single-family houses. Obviously, companies evolve, the financial climate changes and facts may have changed since the case studies were performed, consequently data collected in this project represents a snapshot of the situation at the time of the case studies. However no major changes are likely to have occurred and most probably the case study data represents the situation as of today as well and fundamental issues of industrialized construction remain the same.

This project has focused on the processes involving design and manufacture in industrialized timber house manufacturing. Analyses may be different if at later stages a complete business system of a company would be included. The research is performed in a specific sector, which means that the results consequently will be most valid for this sector. Further, this work will not take market fluctuations into account, as the aim is to address the long-term development of the industry.

There is a difference between what this project aims at compared to BIM. Issues addressed in this project have not specifically been aimed at the design process; instead the target has been customized IT support for the timber house manufacturing industry. The aim of the project has thus been different than to implement BIM in the industry. Instead a broader understanding of how to best leverage the use of IT to increase productivity and quality has been an outspoken goal – of which BIM can be one part.

1.5 Thesis guide

1.5.1 Definitions

Below are some definitions listed which are used throughout the report and that will be of help to the reader to understand.

Building Information Modeling	"*BIM involves representing a design as objects – vague and undefined, generic or product-specific, solid shapes or void-space oriented that carry their geometry, relations and attributes. The geometry may be 2D or 3D. The objects may be abstract and conceptual or construction detailed*." Eastman (2009)
Configuration	Configuration can have several meanings, but generally it includes a process of assembling parts to a complete system that achieves certain performance requirements.
Configuration system	A computer based system that manages and facilitates configuration. Outputs a specification for a customized product based on the configuration rules and the features selected by the user.
Industrialized construction	Focus on processes, product families and IT as the cornerstones of industrialization. Involves prefabrication of construction elements that are assembled on-site, c.f. Lessing (2006) for a complete definition.
Modularization	Dividing a product in parts that encapsulates both geometry and functionality. Modularization make parts interchangeable in order to manipulate functionality.

Product platform	Described in accordance with Simpson (2004), who lists a few examples which proves that product platforms can be defined both broad or narrow: • A set of common, components, modules, or parts from which a stream of derivative products can be efficiently developed and launched • A collection of the common elements, especially the underlying core technology, implemented across a range of products • The collection of assets (i.e. components, processes, knowledge, people and relationships) that are shared by a set of products

1.5.2 Outline

Chapter 1 introduces the report and its outline. It gives an introduction and background to the topic and research area, which leads up to the research questions and objectives of the project. It also defines the limitations for the project and some concepts central in the project are defined.

Chapter 2 gives an overview of the research process and methods used throughout the project. It also explains how data have been collected and analyzed. Research design and validation as well as generalization are explained.

Chapter 3 provides the theoretical framework and gives an outlook of current research within industrialized construction, product modeling and construction IT.

Chapter 4 gives a brief summary of each of the appended papers.

Chapter 5 provides an analysis of how industrialized construction companies can better take advantage of the benefits that their business system provides regarding IT and product modeling.

Chapter 6 contains conclusions of the project, answers to the research questions and contributions made by the project. Further research, validity and generalization are also discussed.

1.6 Other publications

Other publications published during the course of the project on the same topic.

> *Johnsson H., Persson S., Malmgren L., Tarandi V., Bremme J., (2006) IT-stöd för industriellt byggande i trä. Technical Report 2009:19, Luleå Technical University, Luleå*

A report that was an entry point to the configuration research area and a starting point for this project. It serves as background material for this research and facilitated in formulating the research questions. It also provided valuable insights and understanding before this project had started.

2 Methodology

2.1 Research process

The research process of this project has had the character of an investigative study, where one investigation constantly has lead to new questions. Consequently there has been some deviation from the original plan formed in 2006 and the project has taken some turns, which finally has made it to what it became. Hopefully this can serve as a roadmap for industrialized timber house manufacturers by helping them avoid some pitfalls on the road towards industrialization.

Patel and Davidson (1994) state that the research process is about; identifying a problem, literature searching, selecting research design and technique, carrying out the investigation, analyzing, and reporting. This project has followed this process but has been an iterative process where each stage has been performed several times.

The fact that I previously have worked as an IT consultant has helped me gain knowledge in how large scale IT programs are being implemented. My opinion has shifted during the project towards a more pragmatic view where you to some extent have to learn by doing. It has also broadened my view on how IT is considered and treated at large corporations in other industries.

2.1.1 Data collection methods

The research within this project included a number of timber house manufacturers. They all participated in workshops and interviews, individually held at each company. Information was also gathered from documents, mainly related to planning, business processes and technical product descriptions.

Interviews were performed as semi-structured, where there was an agenda and a beforehand agreed upon topic to discuss, as well as some key questions that were the goal of the sessions answer. The interviewees were typically engaged in day-to-day work within the discussed topic at each company respectively.

At several companies we were given access to documents containing information about project planning, which gave us a better understanding of the process. Where available, we were also given access to process maps so that we could further study the processes on our own. At several companies we were also given access to technical product descriptions, so that we could study commonality, number of variants and technical solution designs in order to draw conclusions regarding modularity and suitability for mass customization.

All data collection was qualitative with most of the information gathered on location at the involved companies, which gave us a good understanding for how things work in reality.

Below is a summary of data collection methods used for each paper:

Paper I: A multiple case study, including six Swedish timber house manufacturers. The project team mapped processes and IT usage as well as investigated how products were documented. Interviews were performed as semi-structured individually. Documents were also gathered where possible.

Paper II: Built on data from the case study data as in paper I, plus a thorough literature review as well as further analysis of the material within the research group.

Paper III: Case study performed at a Swedish timber house manufacturer. Semi-structured interviews were performed with engineering and sales staff. We collected the complete technical solution for one product family, which was used to build the data model. The model was later verified via a workshop at the case company.

2.1.2 Analysis of qualitative data

Data analysis has in all papers been performed by a research group with knowledge and experience of the timber house manufacturing industry. Interview results, collected material and data were analyzed together by the research group.

2.2 Research design

The project was divided in three major parts: (1) investigating the current situation in the business, (2) analysis and literature review (benchmark against other industries) and (3) suggesting advice to the timber frame house industry on how to proceed with towards industrialization.

2.2.1 Investigating current situation

The project was initiated with an investigation of the current situation in the timber house manufacturing industry regarding IT support, which throughout the project has served as a foundation and starting point for the other phases. The findings were reported in paper I. In the current situation study, the goals were:

- Investigate processes, IT usage and product documentation in the timber house manufacturing industry
- Conduct a small comparative study at a company in a different industry with the same methods as for the main study
- Present result of the current IT usage situation in the industry

Related research questions:

- How do timber house manufacturers need to develop to adopt configuration systems?

2.2.2 Analysis and literature review

The second part of the project aimed to analyze the data collected in part one of the project. This phase consisted of an extensive literature review and analysis of the data from all case studies. The results of part two was partially reported in paper I and mostly in paper II. Goals of the second part were to answer:

- What methods and tools are used in other industries
- What are the similarities and differences between timber house manufacturing and other manufacturing industries
- Where is the timber house industry today? (benchmarking against other industries)
- What does the timber house industry need to change, i.e. what can they learn from other industries?

Related research questions:

- What effect on the internal systems will a change of the specification process have?
- How can companies proceed?

2.2.3 Advice on how to proceed

A new case study was performed at a timber house manufacturer in Sweden different from the first case study. It had the intention of modeling one of their product series in a product model to explore the feasibility and benefits of using this approach for the industry. This has been reported in paper III. Goals of this stage were to answer:

- Can product modeling be used for timber house manufacturing as a feasible alternative
- Why does the timber frame house manufacturers perform so much individual customization in each project
- How can the customization process be improved

Related research questions:

- Is configuration the right solution to pursue for the timber house manufacturing industry?
- How can companies proceed?

2.3 Considerations

Validity – The project has gathered data mainly through interviews that participants later have confirmed to be correct. This should ensure the validity of the collected information. The authors' experience as a consultant in construction and IT provides a frame of reference that should be relevant when studying the topic of this project.

Reliability – This project has been focused on trying to understand and interpret an industry situation. Therefore it may be hard to reproduce the analysis with the same results. Further, the analysis is performed according to the researchers frame of reference and could produce different results if performed by other researchers.

Generalization – The same methodology could be used to study additional companies in the timber house manufacturing industry. Some caution should be taken when comparing results from this study with other results, as the researchers frame of reference and experiences will affect the results.

Frame of reference – the research group that participated in the studies include people with experience of the timber frame house industry. People skilled in the research area have also surrounded the research group and have assisted and contributed with their knowledge.

3 Theoretical framework

3.1 Current use of IT in the construction industry

IT in industrialized construction is today used according to the same principals as for on-site construction, Johnsson et al (2007), i.e. systems are used separately from each other, which affects collaboration negatively. In the traditional construction process, the lack of integration is handled differently because separate stakeholders manage and own separate parts of the process. In the industrialized construction process however, the same company is often responsible for most parts of the process, thus integrating systems would probably lead to significant benefits. When being able to optimize the construction process as a whole, it becomes easier to avoid sub optimization and utilize the potential to improve overall productivity.

Information management in building design has been identified as a key area for improvement for companies aiming at an efficient building process. The energy put on producing drawings and specifications for each new object today, is often out of proportion compared to the benefit, Nasereddin et al (2007). Consequently IT is a good starting point when trying to increase productivity, but to implement IT companies need to be able to produce formal process maps, product structures and not least a strategy for what they want to accomplish through the use of IT. For IT to make a change, companies need to put more focus on processes, product documentation and strategies, regardless of what software system they may choose to use in a later stage.

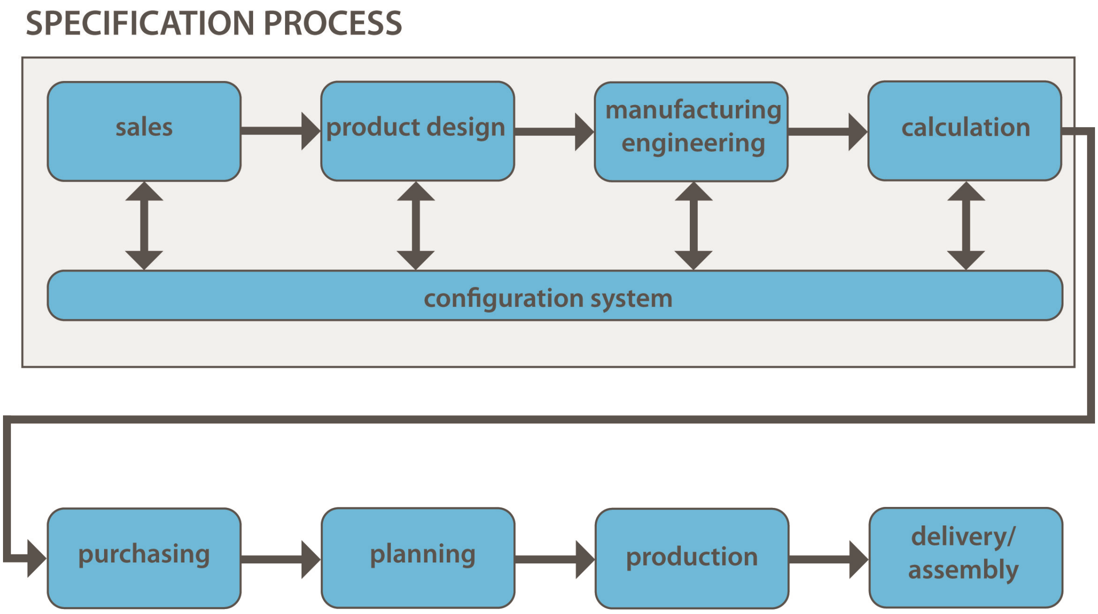

Figure 4 Configuration systems support and integrate he activities in a company's specification process. Adapted from Hvam et al (2008).

From product modeling the step to configuration is not long, configuration can be seen as a way of using the content of the product model to configure products according to customer requirements, Hvam et al (2008). In Figure 4 visualizes an example of the role of a configuration system in the product specification process.

There are two different types of configurators: sales configurators and engineering configurators. Sales configurators are generally used to guide customers to choose a product from the product line or a combination of modules that suits their need. Good examples are *dell.com* or *nikeID.com* where customers by themselves configure their product. To make this work, companies need to document their product variants and relations between the modules so that they can be described in the configuration system or a product model, i.e. all combinations or rules for combinations must be thought out in advance. An engineering configuration system is a tool that helps the engineer to configure the product according to the rules of manufacturing, purchase or other governing rules, i.e. a tool that helps to optimize the product and ensure quality and speed in the design and manufacturing process. This concept is similar to KBE[3], which is further described for timber house manufacturing by Sandberg (2003).

[3] KBE – Knowledge Based Engineering

Different configuration aids are used by different types of companies according to how they approach mass customization, c.f. Figure 6.

Sales configurators are either put directly in the hands of customers or used jointly by a sales representative and the customer, whereas engineering configurations are used in later stages of the sales and design processes and most important, by a different type of user. They nonetheless both have the common goal of making sure products that are sold that can be produced efficiently according to the production system and to eliminate waste in the sales and design processes.

Eastman et al (2009) expect that rule-based systems will become a class of applications that will have a wide deployment in the AEC[4] industries in the future. Eastman et al (2009) categorizes them as follows.

1. For all buildings—general conditions such as building codes, at the national, regional or municipality level of organization.
2. For particular building types—design guides of best practices for a building type; this type of rule-base may be defined by the client organization, or alternatively, as best practices within a design or engineering firm.
3. For a specific building project: programmatic requirements for a building instance, such as its space requirements, circulation issues, ergonomic layout and special site considerations; these may be developed by the client or design firm, and the specific rules defined as part of the program and review criteria during project design and construction.

This shows that the same ideas and methodologies are applied in industrialized construction as for the traditional construction sector, although specific applications will most likely differ when implemented in the industry.

Further, Eastman et al (2009) argues that a rule-based assessment tool can be implemented for various platforms:

1. as an application closely tied to a design tool, such as a plug-in, allowing checking whenever the designer wishes
2. as a stand-alone application running on desktops, in parallel to a design generating tool
3. as a web-based application that can accept design from a variety of sources

This is similar close to how an engineering configuration tool would work in that way that it aim to facilitate the design and configuration effort.

[4] AEC – Architectural, Engineering and Construction

In on-site construction it is commonly the architect that represents the customers interests. In a sales configurator the customer interacts directly with the product portfolio, an approach that most often requires a stricter documentation of the product due the customers lack of understanding of the companies internal processes and structural design guidelines. In sales configurators, it is generally less room for disobeying the design guidelines, as they are absolutely implemented. Requirements must be stricter when the data models need to be checked virtually instead of manually by a human mind, Eastman et al (2009). This imposes stricter rules for modeling when using a configuration approach than it would have been without. One lesson learned is that when aiming at configuration or expert systems, product documentation is a key issue. One way to accomplish a good documentation is through product modeling and modularization of the product architecture; modularization is considered key to achieving low cost customization, Duray (2002).

3.2 How IT strategy and customers need to influence the business model

In the novel *fruITion* by Potts (2008), the author conveys through the book's characters that an IT strategy needs to be focused on creating and measuring business value from the business investment in IT and not as traditionally done, which is starting with IT and figuring out how to deliver business value. Industrialization of the house building sector supports long-term investments at the expense of short term thinking, Ekholm and Molnár (2009), meaning that long-term investments will need to suppress the short-term thinking. This further emphasizes that companies must create an IT strategy that can help them add value to the business and proves to be successful not just for the moment. For example, an implementation of a configuration system cannot only be identified as an IT project, Jorgensen (2005), since then the risk of failure will be significantly higher, moreover there is also a risk that it is not a part of the companies business strategy. This not only impedes the project from success, but also has the potential to diminish the support and understanding of the benefits in the organization.

There is a general need for information management systems that can support the development of product platforms in the product development processes, Simpson (2004). A company's products and processes should be included when shaping the IT strategy. According to Björnsson (2003) the business strategy should generate an IS[5] strategy, which in turn generates the IT strategy, see Figure 5. In industrialized construction, companies need to gain knowledge about information systems, especially in how to use and manage them properly, Gerth (2008).

[5] IS – Information System

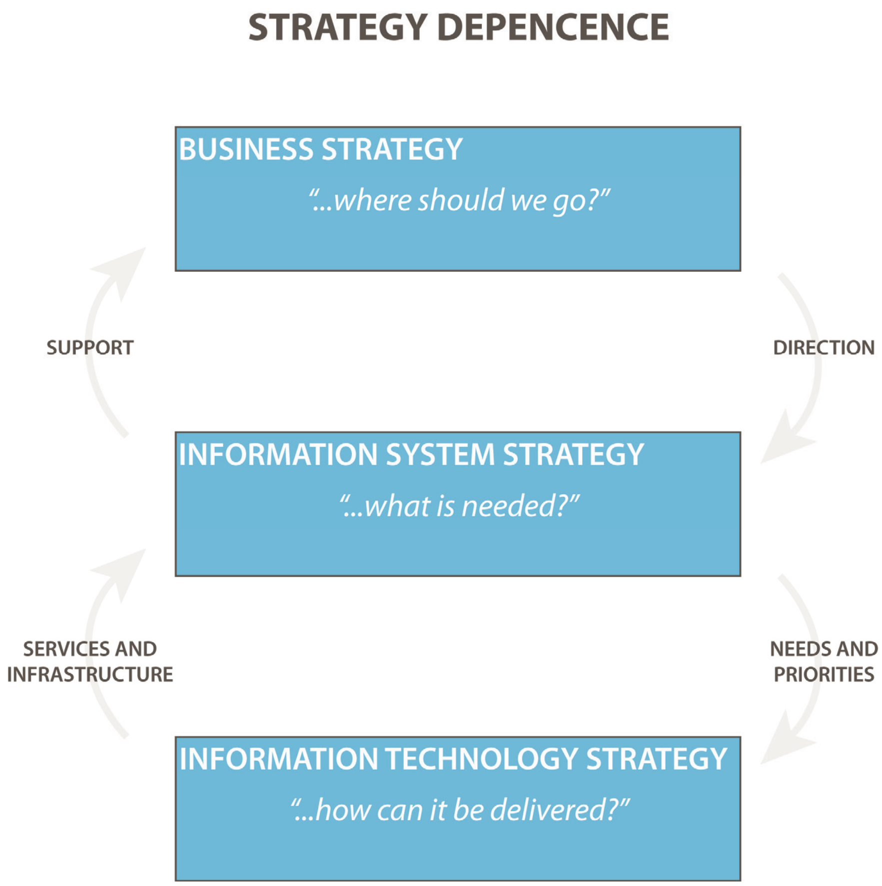

Figure 5 How Business strategy, IS strategy and IT strategy link to each other, adapted from Björnsson (2003).

New business opportunities will arise for companies working with innovative information management solutions, Ekholm and Molnár (2009) and most likely also to companies that focus on the needs in their customer segment. Companies that concentrate on business models that combine IT with the recognition that customer participation is central part of the business, will probably gain an advantage over the competition. IT will be an increasingly important part of how companies interact with their customers, configurators being one possibility of accomplishing this. Today systems for product configuration, which is used in other industries, are relatively absent from the construction industry. Instead customer options and changes are often managed manually, Ekholm and Molnár (2009).

Ekholm and Molnár (2009) describes a part of the Swedish research program IT Construction & Real Estate 2002: *"... focus was lost in the Product model and IFC project, which would have needed a process model and information standardization as a starting point.*" This statement adds to the conception that IT and product modeling projects requires focus to be directed also at business processes and standardization efforts. Introducing product configuration, changes business processes and consequently also how the business system should be formed, Gerth (2008). Therefore product modeling and configuration must be treated as such, not as a sole IT or technical issue, instead the company as a whole must work in the same direction and towards the same established goals.

Today IT managers in construction have a large influence on IT investments, Dehlin and Olofsson (2008), but the level of business integration may be questioned. Consequently, IT needs to be a more integrated part of the business so that investment decisions can be taken based on correct and comprehensive information in relation to business strategies. Companies need to find ways of how to regard IT as a business driver instead of being support function.

3.3 Product- and information modeling

3.3.1 Mass customization

According to Pine (1993) "*customers can no longer be lumped together in a huge homogeneous market, but are individuals whose individual wants and needs can be ascertained and fulfilled*". In the timber house manufacturing industry this translates to that they have to accept that their customers' wants and wishes have to be met in order for them to stay competitive. The construction industry has a history of being skilled in meeting customer requests, their problem instead has been how to efficiently structure and organize customization, Ekholm and Molnár (2009). Consequently their challenge lies in adapting their strategy to include how to meet the needs of their customers and at the same time standardize the product for a more efficient production. Currently we see that the industry could improve themselves by being better at defining their market segment and create a business strategy that integrate their customer segment, products and production system, Malmgren et al (2010).

Mass customization can be defined as building products to customer specifications using modular components to achieve economies of scale. Customer participation and modularity are interrelated and when considered together, they suggest four mass customization archetypes that also imply different manufacturing systems, Duray (2002), see Figure 6. According to Duray (2002), a mass customizer is one of four archetypes, which suggest different manufacturing systems to fulfill customer requests. Fabricators are the mass customizers that mostly incorporate craft manufacturing practices – this is also where most timber house manufacturers currently can be found. In the future however, timber house manufacturers have the opportunity to move towards being involvers, if they adapt more defined product models and processes, which could help them move their modularization- and customer involvement point.

Mass customizers are divided according to following characteristics, Duray (2002).

- Fabricators – Include both customer involvement and modularity in design and fabrication stages of production. Unique designs can be realized or major revision can be made in the products. Fabricators resemble a pure customization strategy but uses modularity to increase commonality of components.
- Involvers – Incorporate customer involvement in product design during the design and fabrication stages but use modularity during the assembly and use stages. Customers are involved early in the process although no new modules are fabricated.
- Assemblers – Mostly resembles standard producers, employs modularity and customer involvement in the assembly and use stages. Assemblers use modularity to present customers with a wide range of choices. Assemblers differ from mass producers in that the products have been designed so that the customer can be involved in specifying the product.
- Modularizers – Modularizers involve customers during assembly and delivery but incorporate modularity earlier in the production cycle, in the design and fabrication stages. Thus they may not gain full customization advantages from modularity. Together with assemblers, modularizers most closely resemble standard product producers due to the late point of customer involvement.

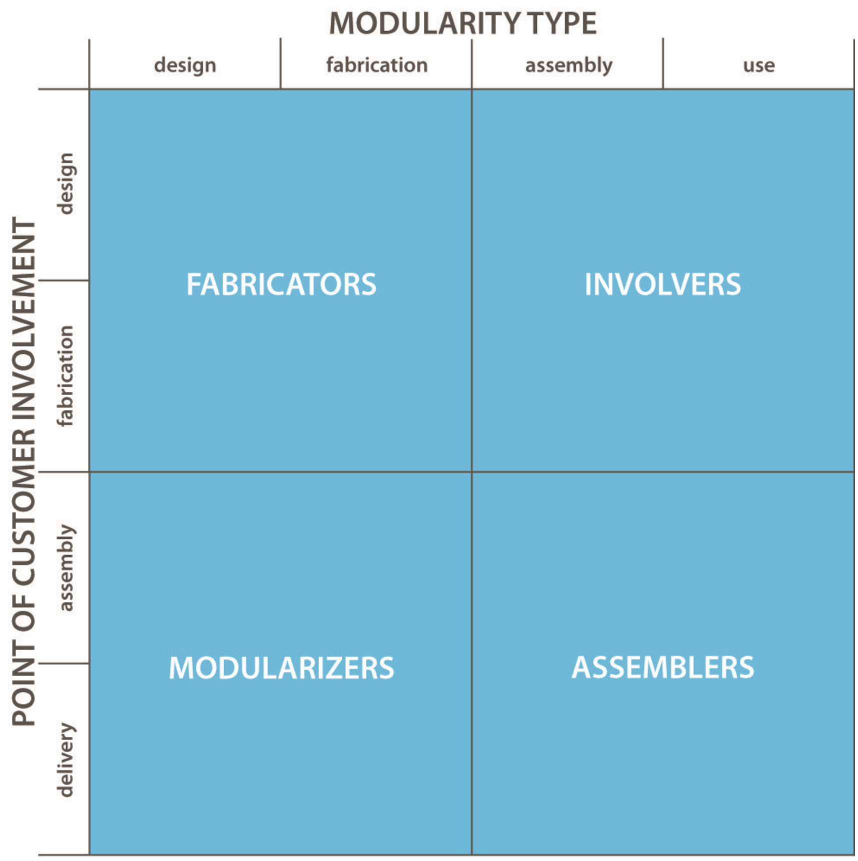

Figure 6 Mass customization archetypes, point of customer involvement and modularity type. Adapted from (Duray 2002)

Figure 6 shows the four different archetypes of mass customization, which also suggest different manufacturing systems. The figure explains where modularity is introduced and where the customer point of involvement lies. This model could be applied to identify industrialized construction of to day as well as be an aid when discussing a future strategy.

Mass customization could be one alternative for the timber house manufacturers to approach the issues that is currently troubling the industry. It has the potential to help them develop their business strategy to incorporate better customization opportunities, governance and a more effective manufacturing system that better integrates with the product portfolio.

Globalization of markets has fundamentally changed the competition for manufacturing industries, which have forced them to become increasingly efficient in product development, Simpson (2004). The same development has begun to show in the construction industry, for example in Skanska ModernaHus, Skanska Xchange, PEAB PGS etc., but there is still a long way to go. Several industrialized concepts are analyzed and presented in Andersson et al (2009). The pressure to change has not been as significant in the construction industry as in other manufacturing industries. But the industrialized construction industry's struggle with quality, cost and reliability could be addressed by including influences of mass customization. Change will most probably take hard work and commitment; mass customization and product configuration require interaction and communication of information between market, sales, product model and production system within the company, Gerth (2008). Consequently companies need to focus on integration and communication, which will inevitably make IT a significant part of the solution. Simpson (2004) concludes that "*we must strive to understand the organizational impact of platform based product development better*" indicating that also the organizational structure of companies will be affected by a shift to mass customization. Industrialized construction companies that consider pursuing mass customization must be prepared that it will mean changes not only to the products, but also to production system and organization.

3.3.2 Product modeling

In an interview an employee from the heavy truck maker Scania explained, *"More customer choices mean that you have to have more control of the production, so that the product with its promised properties is possible to produce.",* Gerth (2008). For the companies participating in this project, it has been common to allow customers a great deal of freedom when it comes to what they can change in their order, but from what we have seen there is not a corresponding strict control of the production. The production in many cases resembles on-site construction and instead of industrializing, they are applying the project oriented construction process.

One additional factor to consider is the software market for construction IT and BIM applications. Dominant software manufacturers like Autodesk, Bentley Systems and Graphisoft would most certainly like to influence how companies formulate IT strategies, which also influence integration and cooperation within the company. BIM has become the prevalent strategy to pursue for on-site construction and the market for BIM tools is constantly growing larger, Eastman (2009). To gain control over the process, timber house manufacturers must find inspiration also elsewhere than in construction in their search for IT and how to design processes. Simpson (2004) lists several projects within the area of product platform design and customization, which shows that the technology exists but implementations in construction are not widespread. The task ahead for the timber house manufacturers is not to invent or develop new IT-systems, but to apply existing technology on a new market.

Scania has defined their product model as a model from which all trucks from a specific series are configured. The company works according to the outspoken principle "same need – same solution", i.e. the same customer need should always be fulfilled with the same technical solution. This requires product structures that are formalized and well set in the organization. According to Scania, this is key for minimizing the number of technical solutions, Gerth (2008). Scania has successfully identified and delineated their market to be able to apply their product model effectively, Gerth (2008). They have most likely realized that their business model cannot appeal to all customers wanting to buy a new truck, instead they have focused on satisfying the needs of their specific market segment.

In Hvam et al (2000) a process for designing and implementing product models is described. The model includes the steps of product range analysis, product structuring, software design and implementation. With this model, process, IT and product are addressed, areas that need to be accounted for when aiming at implementing configuration systems. Common for all product models, are that a it needs to a selected portion of the reality with formalized and structured information.

BIM has grown to become synonymous with product modeling in construction and can be regarded as the fastest growing methodology to manage data throughout a buildings lifecycle. BIM is primarily used as a way of integrating different disciplines in the design phase of the traditional construction process. Compared to product modeling, BIM is primarily developed with the traditional building process in mind, whereas the methodologies for product modeling are more general and have the ability to appeal companies in all industries. BIM has been an umbrella under which development of tools and processes specific for the construction industry have emerged. Furthermore product modeling is more used in a product development process that then leads to a production phase thus the product development is a large effort separated from the production phase. BIM on the other hand has its main application in the production phase of construction.

To sum up the above mentioned facts, BIM is more of a tool for integrating the parade of trades in the traditional construction industry and not really developed for the needs of industrialized construction. Industrialized construction could better benefit from general product modeling, which could allow them to better separate product development from production.

3.3.3 Product platforms and modularization

Product platforms and customization are getting particularly interesting for small- and medium sized companies. The ability to develop platforms that can leverage a variety of functions requires by the customers are getting more and more important in order to remain profitable, Simpson (2004). This could prove to be a way forward for the timber house manufacturers that do not build that many products of each series per year and thus need to share as many components and structural designs as possible between the products. Mass customization paradigm has however not yet reached construction in general. Although mentioned as an inspiration to the NCC Komplett program, Gerth (2008), mass customization is seldom described as a way forward for the construction industry.

Modularization is one way of reusing product knowledge in new products, instead of creating unique one-of-a-kind products. Some positive effects of configuration is summarized in Johnsson et al (2007). Drivers for modularization include: increased product variety, reduced complexity, increased commonality amongst others, Erixon (1998). Despite the benefits, many companies in the manufacturing industry are hesitant to enter the world of product modularity because of fear that they will loose their competitive advantage on a relatively small market, Simpson (2004). But looking at the PC industry, open product architectures have proved to be a success.

Modularity is a relative property, Ulrich and Eppinger (2008) and product is rarely strictly modular or integral. Instead products generally have varying degrees of modularity – so one can seldom say that a product is strictly modular or integral. Modularity has been the theme of many books and research papers, for example in Simpson (2004), Ulrich and Eppinger (2008) and Erixon (1998), but applications in construction are still unusual.

Product family maps and market segmentation grids are tools that can support planning from a management perspective and can help to get started. But these aids are of little help to engineers that need a much finer level of detail to set the product platform components and commonality, which is part of the platform development, Simpson (2004).

A product platform can facilitate customization by allowing a variety of products to be quickly and easily developed to satisfy the needs and requirements of specific market niches, Simpson (2004). When discussing product modeling, modular product structures are hard to exclude, but there is a difference between variety and customization – variety implies more products to choose from, but does not allow the customer to specify any product features, Simpson (2004). Large product variety can inflict substantial cost in a company, so in fact – more product variety means higher costs, Simpson (2004) and Ulrich (1995). What companies need to focus on, is to reduce complexity of the product models and make them work as simply as possible. Set the universe of discourse to what the intentions of the model are, the leaner companies can make the model, the more effective it will most probably be. MFD[6] is presented as one of several methods to modularize a product family based on the features required by customers, Erixon (1998). Applying methods like QFD[7], Akao (1990), might be easier in industrialized construction compared to the traditional construction process due to that they own a larger part of the process. This might be one way to go for timber house manufacturers aiming at mass customization.

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[6] MFD – Modular Function Deployment

[7] QFD – Quality Function Deployment

According to a recent Accenture survey, Accenture (2009), masters in product development distinguish themselves from laggards by:

- Aligning product development strategy with their delivery capabilities
- Engage product brand engineers in initial design, use customer surveys and warranty data to improve design
- Integrate suppliers and partners into new product development processes
- Reduce complexity by designing new products as platforms, enabling them to use up to 70 percent of an existing design
- Reuse parts from previous products
- Use long planning and concept cycles that reduces time to launch

This implies that pursuing product platforms as a strategy could provide benefits like more reuse of designs and parts, as well as shorten the time spent on every project.

3.3.4 Configuration

In the last years the industry has inclined towards changing the specification processes so that companies have better possibilities to adapt to customer needs, Hvam et al (2008). Today, timber house manufacturers manage production separately from design and product development. Product specification processes that have given too little attention to customer requirements during product development, result in many ad-hoc solutions and a high degree of customization, which in turn leads to higher costs and unpredictable quality. Configuration has the potential to bring better control and process orientation, Männisto et al (1998) and Jorgensen (2005). Using configuration would also be an indication that companies are adapting to the concept of mass customization (c.f. chapter 3.3.1), which also affects products and organizational structure of the company, Duray (2002) and Simpson (2004). Product specification processes can vary from a high degree of freedom for specification to very low, Hvam et al (2008). This suggests that companies have good possibilities to adapt a product specification process (configuration) to their own needs.

3.3.4.1 An example of configuration

In Hvam et al (2008) the use of product configurators is exemplified by a project at the company F.L. Smitdth A/S. To give the reader an understanding of how a configuration system could work, the most important parts of the example is summarized in this section. The company F.L. Smidth A/S supplies factories for cement production to their customers. Cement factories are designed according to several parameters, such as raw materials, capacity requirements, emission requirements etc.

The most important customer requirements for cement factories are listed as:

- Price and financing conditions
- Delivery time
- Operating costs
- Energy consumption

Incentives at the company for using a configuration system has been that they need to be able to produce a binding offer as well as they feel that they use a large portion of their resources to produce offers. With this background in mind, F.L. Smidth decided to develop a configuration system for budgetary offers. Figure 7 describes the gap between how the offer process performs today and where they would like to be. Before using the configuration system, several departments were involved and significant resources were spent on coordinating the information flow between departments. A budgetary offer usually took 25 man-days to produce.

	Target	Current performance	Gap
Lead time	1-2 days	5-25 days	To be reduced by about 50-90%
Resource consumption	1-2 man-days per budgetary offer	About 25 man-days per budgetary offer	To be reduced by about 90%
% enquiries which are replied to with an offer	100%	50%	50%
Quality of budgetary offers	Uniform budgetary offers	Large variation	More uniform offers

Figure 7 Gap analysis for a configuration system implementation, Hvam et al (2008).

Initially in the project, considerable efforts were placed on making sure to set the limits for the configuration system, so that the system could be implemented correctly. It turned out to be difficult to describe the process of making an offer. As they were trying to establish a process, it turned out that the process differed from project to project and depending on who was involved in making the offer. This also meant that the offers could vary significantly in quality, depending on who had been involved.

The project started off with identification and analysis of the most important specification processes. To be able to estimate the potential of the configuration system it was necessary to do an analysis of current offer process, summarize the most important aims of the offer process and the current performance, as well as creating a vision for how the system could contribute in the future.

When working with the configuration system, F.L. Smidth now uses a new process for creating offers, which is supported by the configuration system. The configuration system can be used by a sales person, who determines all necessary inputs into the configuration system together with the customer. Another scenario could be that a salesperson together with a specialist at F.L. Smidth inputs data in the configuration system, based on a customer request. The overall process for the new offer process is described in Figure 8.

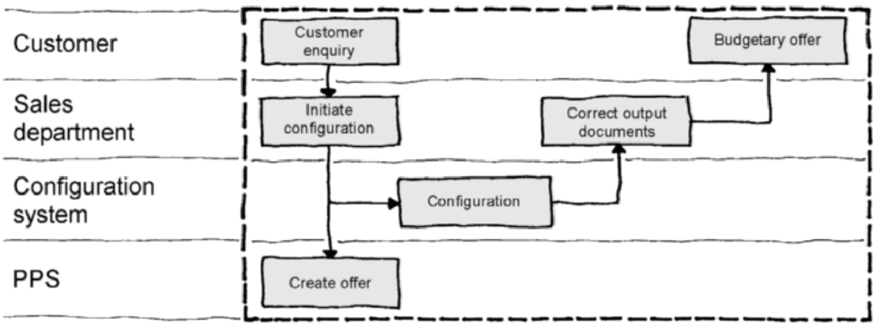

Figure 8 Overall process with budgetary offers and detailed offers after introducing the configuration system, Hvam et al (2008)

The budgetary offer is created as a Word document. A budgetary offer is typically 100-200 pages long. In the specific system at F.L. Smidth, the output consists of:

- Content overview
- Price estimate
- Project parameters (operating times, capacity, emissions etc.)
- Process diagrams for the entire factory
- Process diagrams for the factory departments, including machine descriptions
- Layout proposals
- Descriptions of main machines
- General descriptions of electricity supply and controls
- Timetable

One of the most important benefits is the ability to guide customers to choose a standard product, rather than a tailor-made solution. Custom solutions mean a higher workload, resulting in delay and uncertainties for the project. Further, F.L. Smidth's staff sees the configurator project as a way of formalizing and sharing knowledge about the company's products.

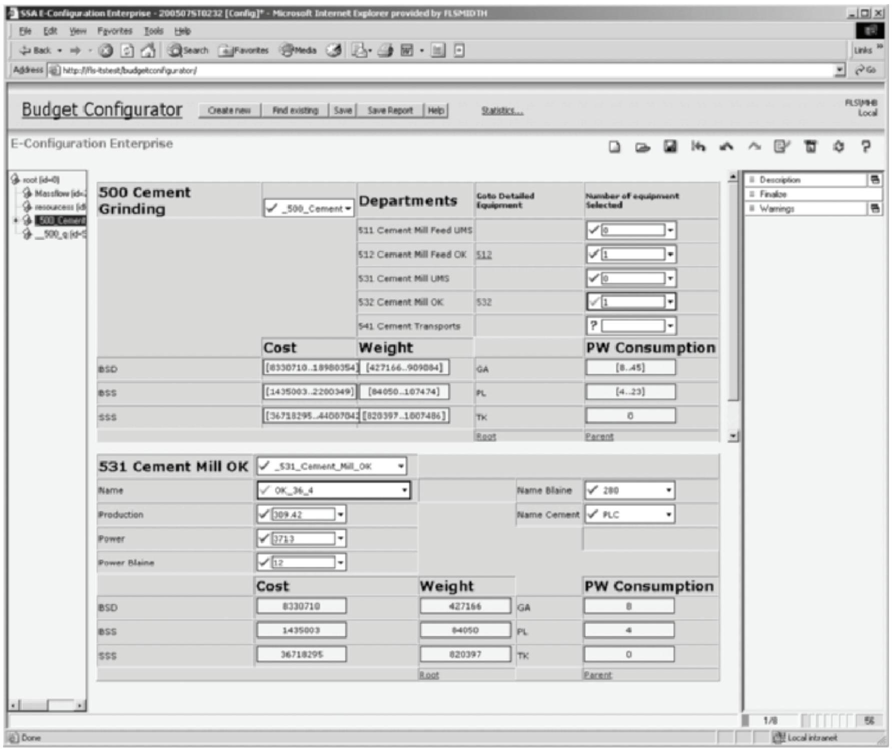

Figure 9 Screenshot from the configurator, Hvam et al (2008)

The user interface of the configuration system follows the flow of materials through the factory, see Figure 9. F.L. Smidth chose to use the commercial configuration system E-Configuration Enterprise from Infor for their implementation. Due to earlier experiences, they decided to design the configuration system as a standalone system with no connections to their other systems. The first version of the configuration system was implemented in 2000. As an example of benefits, the use of the configuration systems has meant a better structure for the customer negotiations, see Figure 10 for a list of costs and benefits for the project.

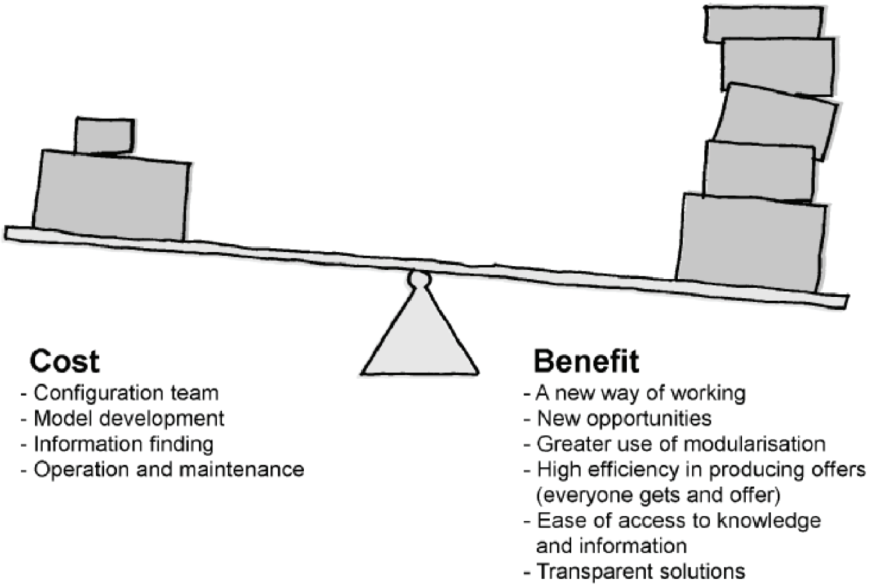

Figure 10 Costs and benefits from using the configuration system at F.L. Smidth, Hvam et al (2008)

3.3.5 Bringing mass customization, modularization and configuration together

By leveraging mass customization, modularization and configuration, companies are given the opportunity to change their business model to be able to more efficiently meet customer needs, while at the same time improving quality through standardization. Mass customization becomes the overall paradigm for the business and modularization becomes a product strategy that helps companies to meet customer demands effectively. Configuration then becomes a way of interacting with the customers. By allowing them to use the configuration tool, they can choose product features by themselves and thus companies can better include the customers in the product specification process.

A more flexible product family has the potential to meet customer needs effectively. Modularization suggests that the product platform consists of modules that can be put together in different combinations to suit the needs of the customers by using, for instance, configuration. Product platforms play a major role in facilitating the customization process, Simpson (2004) – which explains how modularization and configuration are related to each other.

4 Summary of papers

4.1 Paper I: ICT support for industrial production of houses – the Swedish case

This paper is built on a multiple case study of six medium-sized timber house manufacturers. The study focused on finding elements that could be included in an information strategy suitable for industrialized construction. The paper also presents several different methods for documenting products used in other industries. The analysis suggests that companies need to look beyond traditional construction to improve information management, instead of only glancing at traditional on site construction.

The paper introduces some properties an information strategy for industrialized construction should contain. The timber house manufacturing industry operates on different conditions compared to on-site construction and consequently requires a different information strategy. The feasibility of using some product modeling tools already established and used in other industries is discussed.

The paper concludes that the timber house manufacturing industry could improve quality, reliability and productivity by taking measures to address their current issues with information management found in the multiple case study. This article mainly establishes the current situation in the industry and suggests several different directions that can be pursued by companies to address their situation regarding IT and product documentation.

4.2 Paper II: Information management in industrial housing design and manufacture

This paper builds on the same case study data as for paper I, however this article analyzes the collected data from a different perspective. The concepts of product modeling and modularization are identified as a prominent way forward for the industrialized construction industry. Product modeling is explained and the paper describes how the concept is used in other industries. Moreover, the paper explains that industrialized construction companies need to put more focus on information management.

Timber house manufacturers need to focus three areas; process orientation, product documentation and information systems strategy. Companies need to take on the industrialization journey by themselves, progress in these areas cannot only come through joint industry progress and IT solutions need to be adapted to each individual company. Further, the business could look at if they could benefit from implementing a product development process.

4.3 Paper III: Product modeling of configurable building systems

The third paper takes on testing product modeling in a case at a Swedish timber house manufacturer to investigate the feasibility of using the approach for the industry. A Swedish customer survey which rank features that customers prioritize when buying detached houses are compared with what the company's product platform currently can offer. It is concluded that the technical platforms are not entirely matched with the customers needs and that may be a contributing reason for why there is so much customization in each project. Product modeling can be used as a way of documenting the product for internal use, as well as a way of keeping track of features and commonality put down on each model. The information model created was structured in four views to reflect the information needs of customization, engineering, production and on-site assembly. Information exchange between the four views is essential for good customize-to-order configuration and has the potential to give companies a better overview of the product family.

It is again concluded that companies by themselves must initiate these kinds of initiatives and new product features should be added in a product development process as a strategic decision. It was observed that companies are generally better at transferring information downstream the value-chain than upstream.

5 Utilizing the benefits of industrialization

This chapter will first summarize the analyses from paper I-III and describe what industrialized timber house manufacturers can better utilize product modeling and configuration. Primarily this will be focused on better utilization of IT and product data modeling, but introducing the two will also affect current processes and probably change the organization, Simpson (2004), thus all four areas needs to be considered jointly.

5.1 How the industry can face their challenges

The included papers describe how a more strategic approach to information management and deeper understanding of product data management is currently the first and most important steps for companies trying to raise efficiency in the timber house manufacturing industry by using IT. Change will need to come progressively as these initiatives will probably bring fundamental changes seen over a long period of time. There must however first be a better understanding and a more entrepreneurial discussion in the industry for how IT can help drive business forward. Many product-modeling techniques exist today, but few companies in the timber house industry have so far taken advantage of them. One reason for this could be that product modeling is a progressive journey where you need to learn by doing, waiting for an industry standard to emerge will simply take to long.

Configuration and product modeling should not be allowed to be considered as sole IT projects, a fact that is also mentioned by Jorgensen (2005). The primary benefits of product modeling have been described as better control, quality and increased interaction with the customer, Männisto et al (1998) and Jorgensen (2005), benefits that are all in the interest to management – not just for an individual department or group within the company. Incentives for starting efforts that address quality, customer value etc., should naturally come from, and be supported by the management. The support is not necessary just for projects to be successful, but also to receive adequate support and assigned resources during the course of the project. Implementing IT projects has been proven to be a multifaceted effort that will affect a vast number of functions within an organization. It will likely have some effect on everything from organization to product documentation. Therefore it is important that the ownership of such a project lies relatively high in the organization.

5.2 A different point of view – an abstract view of product data

The four different views described in paper III (customer, engineering, production, site) could be equated to the different stages of QFD, in a way both the views and QFD describe the transformation process of customer requirements to an actual product. So by adapting the view scenario from paper III, companies potentially gain a better understanding of the process for efficient customization as well as getting a better structure for meeting customer demands. The views could also be used as an abstraction of the product to facilitate the transition into a product model based design method. By dividing the product in something similar to LEGO-pieces that encapsulates functionality as well as geometry, it will become easier to overview and explain what the product can and cannot do – both internally as well as to customers.

Basically the use of an abstraction model is about finding a proper structure for transferring customer requirements to technical solutions that can later be manufactured. In the manufacturing industry this is performed once – in product development. In construction however it is performed in most of the projects, which is a huge difference between the industries and something that currently must incur major costs as well as make companies more reluctant to customize as it adds lead times to projects. This further implies that companies should have a rigid process for customization; studies in this project have found the opposite – companies are often very open to customization.

5.3 Align processes with information systems and products

It is clear that companies need to give process design and implementation some focus, not just per each department – instead they could take a holistic perspective and include the process from sales to delivery as one issue, which spans over multiple departments. Based on the interview findings, companies do not use the benefit of owning the complete process as much as they could, something that is a major potential benefit compared with traditional construction. In some ways they still treat every order like a traditional construction project, where each department represents a stakeholder in the construction process. This mindset is also reflected in their approach to product development, which is partially managed in each order. However new products are to some extent developed in a separate process, companies are lacking a strategy to include all customer requirements, which leads to much customization in each project. If they instead could start with a blank paper and try to organize themselves so that they can deliver as much value as possible to the customer and streamline internal work, the process would probably have more resemblance to other manufacturing industries. During one of the interviews, an employee expressed that they see themselves more like an engineering company than a manufacturing industry.

Companies included in the study show somewhat different business models, but they all share the absence of an outspoken focus on an organization focused on efficient processes and effective customer request fulfillment and communication. Instead customer wants rule the production, which sometimes has to be bent backwards to produce what has been sold. Including customers early in the product specification process is a critical factor for a successful platform customization, Simpson (2004). This needs to be prioritized in the industry based on the findings in this project. One explanation to that companies are not having well defined processes may be that the building system is not static, which according to Gerth (2008) also affects processes. Therefore, a less strictly defined product will give companies problems when trying to design processes. This means that it will be crucial for companies to find the root causes to their issues before moving forward.

Companies working directly with consumers start their involvement in the sales process late, instead several companies contract independent sales representatives to manage customer contacts, the company does not act until a contract has been signed and initial design has been set (based on centrally distributed material). This setup diminishes the company's direct link with their customers and introduces a firewall between customers and company. Ideally, companies would dictate the conditions for the sales process (as well as be directly involved in the process) as it sets much of the customers expectations and design parameters. Their involvement in the process would be especially beneficial as they are having issues with controlling information flow throughout the process.

Companies that operate under the GPA[8] on the other hand, state that they want to enter the sales process as early as possible. Entering the process late means that the specifications for the building are already set, which makes it hard for them to produce a tender that meet all requirements and maintain a competitive price.

In common for all companies participating in the study are that they enter the sales process relatively late, which must make it much harder for them to gain control of the process and the product customization. As mentioned before, none of the included companies have a distinct product development process, as could be the case for a company working according to mass customization principles. During the course of this project, no product development process has been identified nor has any through description of the building system been found. So, on what information do companies for example automate production and take strategic investment decisions that affect their product portfolio over a long period of time? One obvious risk with lacking an overview is that it will be harder to take well-informed decisions that will support the business.

Customer requests may often be fulfilled in different ways, which indicates governance issues. Since the customization process can be seen as a key process that should be central for companies when trying to deliver value to the customers, this means that they would want to have as much control as possible over this process. One way of gaining more control over the process would be to use a configuration system to help them convey current delivery capabilities and configurations directly to the customer. This would allow them to keep using the sales representative, but gain more control over the configuration process.

[8] GPA – Government Procurement Agreement

5.4 Adopt new and relevant IT

There is much that can be done in terms of IT, especially when it comes to integrating systems and data sources. Papers I-III have shown that it is not about finding the ultimate IT-system on the market, it is about finding the right level of support suitable for their needs. Further, it is about robust implementation and finding an appropriate IT-strategy that works.

In several of the case companies, IT is not seen as a primary driver for business, thus the willingness to adopt new IT, as well as their maturity, is generally a bit lower compared to an industry average. One root cause could be that CTO[9]/CIO[10]'s lack internal support from the management or does not hold a strong internal position – which further implies that IT does not drive the business, at least not in the eyes of the management. As the industry organization for industrialized timber house manufacturers is relatively strong, there is a discussion, which could work as a way of spreading information. However, development will probably not come primarily from here.

The Swedish construction program *IT-build*, which ran from 1991-1994, concluded that the "*industry's capacity to use IT for increasing competitiveness was too low*", Ekholm and Molnár (2009). It still remains to verify how the industry has evolved since, but their results coincides with the observations in this project – companies need to increase their general level of knowledge to be able to use IT effectively as well as to use IT as a business driver. Companies do not primarily need BIM, instead they need an IT platform that supports the specific processes and business model of industrialized construction. Industrialization should not only change the perspective of the manufacturing system, but consequently it also changes IT strategy and processes. Reviewing the precast concrete company in paper III, it becomes evident that systems integration initiatives have to be managed by each company individually, it is not a feasible solution to wait for the industry as a whole to solve issues that can be very different from company to company. Hopefully, one successful IT project implementation will lead to another and give momentum to the industry, since the intangible benefits of IT projects are somewhat difficult to predict and measure, Dehlin and Olofsson (2008), companies will need to rely on experiences from companies in the same industry.

If companies were clearer in identifying their interfaces towards external stakeholders in addition to specifying what they want to accomplish through the use of IT, it would be easier to establish what tools they can and cannot use. Measures taken might impede productivity temporarily, but will hopefully prove beneficial over a longer period of time.

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[9] CTO – Chief Technology Officer
[10] CIO – Chief Information Officer

5.5 Product data management

The industry has a challenge in how to formalize tacit knowledge, which constitutes a significant part of the current product knowledge. This knowledge has to be formalized somehow if aiming to form a product model. This also raises issues of how to store and manage this information. There is a lack of overview regarding product knowledge in all companies that participated in this project, they rather keep a loose product description as there often are conflicting views and opinions. Ability to manage product data in an organized model needs to be considered a strategic asset of the companies. If companies were to go ahead with a product modeling project, difficult considerations have to be made regarding what products should be included in the product model. The extent of the model will depend on what the companies want to accomplish. There are several management decisions that have to be made before a project can start, which links back to that management must lead such an effort.

One way of formalizing tacit knowledge would be to identify and establish different information views based on the product data to represent different user scenarios in the organization. The product modeling approach will only be as successful as to the extent it is used in the organization, which is why thorough analysis work needs to be completed before design and implementation. Therefore the suggestion would be to implement an abstract company view that divides the company based on different information user groups, which also represents different stages of the process, see Figure 11.

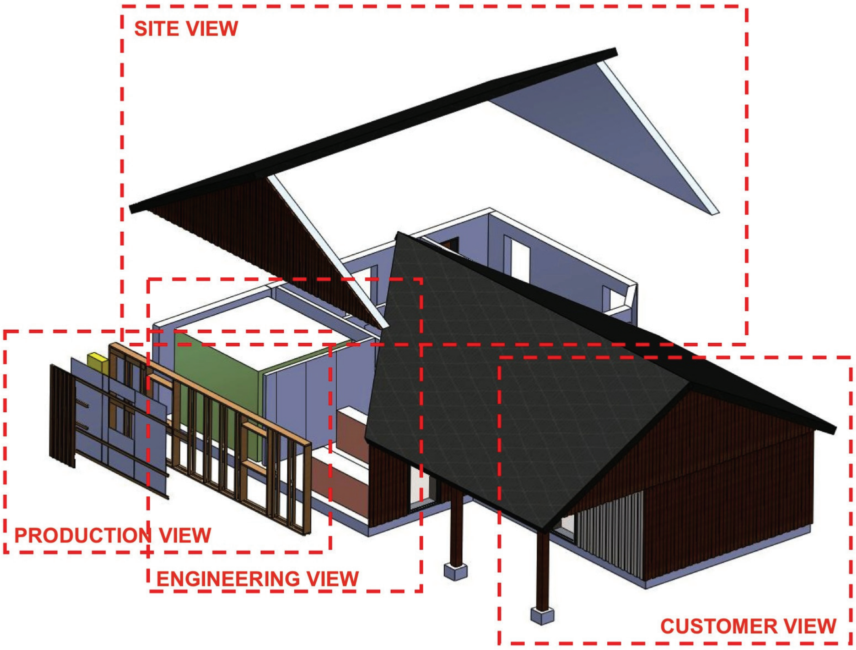

Figure 11 The four information views, Malmgren et al (2010).

There are information gaps between different processes at the majority of the studied companies, however all root causes to this still remains to be identified. The lack of a rigid product description nevertheless makes it hard for companies to adapt to changing customer needs because of the insufficient information flow – poor documentation makes it hard to set boundaries for what the customer can and cannot do in the customization process. In all companies that participated in the project CAD-software is the predominant product description system, which makes engineering a strong stakeholder at the companies. It has proven hard for companies in the industry to develop product platforms for several reasons; instead customer requests have been met with ad-hoc solutions, which lead to propagating design errors and product families that are growing uncontrolled. One reason for this might be that product platforms have evolved over a long period of time without adequate control and governance, Brege (2008).

The four different information views; customer, engineering, production, site can be used by the business as an analysis model to evaluate how well companies are at transferring information within the organization. For example, the model could be used to analyze how well companies are connecting the four views to transfer information and help them evaluate their current situation. It has previously been established that configuration systems brings both increased quality and control to an organization, Jorgensen (2005) and Männisto et al (1998), which is exactly what the companies in the timber house manufacturing industry need. Enforcing a strong structure or a model through a configuration system, will facilitate the transition to an improved state of information management and force the companies to continually work to better organize processes and product documentation. At all participating companies they especially have problems with transferring information upstream. To be able to transfer information internally, companies need to connect the four different views, which have not been observed during this project. Companies could also use the views as an abstraction model of the product to facilitate the transition into product modeling.

6 Concluding discussion

Configuration and product modeling is an opportunity that each company should consider, but they need to remember that it may not be suitable for all. However, during the course of this project there has not been a strong response from any of the participating companies. Several companies have initiated some efforts, but the general conception at the end of this project, is that the level of understanding regarding product modeling needs to be increased to attract interest in the business. Each company also needs to figure out how they should approach industrialization for themselves. In this process the only thing the research community can contribute with is showing what alternatives that exist.

During this project we have most often approached the engineering staff of the companies – a decision that in retrospect may have proved to be too narrow. We would have needed to get more insight from other departments to understand their situation in order to expand this project and make it more generally valid. Although starting as a project with a technical focus, where configuration systems were the primary aim, this has taken a turn towards addressing underlying management issues, which in fact hinders companies from implementing IT. To summarize, there are other issues that needs to be addressed jointly before the full potential of a better IT environment can be realized.

There are no easy nor any definite answers to the research questions that started off this project. From being a rather technical project at the start, the findings have made the project more inclined towards trying to understand how management and organizational issues affects an implementation of a configuration system as well as what an implementation requires from a process and product documentation perspective. I.e. the project has more come to focus on reducing the knowledge gap that the industry is currently experiencing in IT and product modeling. The research questions as well as the answers are an effort to point out how companies in the timber house manufacturing industry need to focus in order to implement configuration. Nevertheless each company must find their own path suitable for their specific business strategy.

6.1 Addressing the research questions

6.1.1 Research question #1

How do timber house manufactures need to develop to adopt configuration systems?

From the research performed within this project three areas have emerged that needs special attention from companies that want to pursue configuration: IT-environment, product documentation and business processes, steps that all will lead companies towards more efficient state.

During this project it has become clear that it is not one isolated issue that constitutes the problem for the industry. Instead several interconnected issues form the situation they are experiencing today – for that reason it has proven rather difficult to sort out the root causes that explains current circumstances. To prepare for configuration, some measures need to be taken to close the gap between current situation and one where product configuration manages the specification process.

6.1.1.1 Improving the IT environment

Every company must be able to define what they want to accomplish through using IT by themselves. Reviewing the precast concrete company in paper III again made it clear that they have to act individually and all companies have different starting points and thus different roadmaps as well as different goals. But common for all companies is that they need to increase the general level of IT knowledge to be able to define their own needs as well as how to adopt and effectively use new technology.

The roles and responsibilities of the CTO and the CIO could be defined more thoroughly in many companies as well as how they interact, which would lead to a better environment for integration. There is also a need to emphasize how the IT strategy creates business value for the company.

6.1.1.2 Better correlation between processes and business model

Part of the underlying issues in the timber house manufacturing industry is that companies may find it hard to position themselves. In many ways they identify themselves with the on-site construction industry, but the two sectors do not compare in more than one way. Timber house manufacturers have a potential in being better at utilizing the benefits in their business model and they could distance themselves by developing their processes to fully utilize their business model.

Product customization must be seen as a key process that should be central to the companies. Therefore it seems peculiar that many of the companies let external sales representatives manage parts of this process. If their goal is to deliver maximum value to the customer, then they should not use the sales representatives as a firewall between the customers and those who are knowledgeable about the product.

A suggestion would be to change the sales process so that it better connects the company to the customer as well as to investigate how configuration systems could better connect customers to the product specification process. Clearer processes would also most likely help in separating the product development from the product specification.

6.1.1.3 Rethinking product documentation

Product documentation within the companies could be better; stricter and more formal, less tacit. Product modeling has the potential to help companies to better structure and formalize knowledge. Tacit knowledge has during this project been seen as one of the major issues when trying change the product documentation so that it can be the foundation for a configuration system. It is hard work and does take time, but dealing with product documentation will be essential for companies that wish to implement a configuration system.

What companies can do is to find out what the current status of the product documentation is. Find a product modeling method that levels with the ambitions of the company. Also be sure to include own staff so that the knowledge is preserved after the project is finalized.

6.1.2 Research question #2

How will companies be affected by a change into configuration and product modeling?

6.1.2.1 Organization

This project has concluded that the industry has not fully realized the effort it would take to implement a new IT system that will have an effect on several parts of the organization. It will affect organization as well as processes and companies need to learn how to effectively deal with the changes. IT can most certainly be used as a competitive edge when organizations learn how to effectively deal with the change that a large implementation will bring. Currently, companies are possibly also suffering from their heritage as a construction company when they in fact have more in common with manufacturing industries. All companies that participated in this research show a strong resemblance with traditional construction companies, although this may not be optimal for their industrialized business model. What we have seen in some case studies is the clash between the internal organization and the interfaces with the project oriented construction industry, this poses one hindrance in becoming a mature manufacturer.

Companies need to start by reviewing the organization and how it aligns with the business model. They also need to decide whether they want to be a house manufacturer or a construction company and how that affects the business model.

6.1.2.2 Product development process and product architecture

The fact that companies do little work in the product development process means that customization becomes an extra development cost in every project – thus this might make companies reluctant to make changes that the customer wants to have or see it as a burden. This might be an indication that the current organization may not be optimal for factory-based construction.

Current products can most probably work as a base for future modularized product platforms. What companies need to do is to sit down and figure out what features should be left in and what to phase out so that the product model not will be too ambiguous, i.e. they need to figure out what products to market in a configuration system.

New product features should only be introduced as new products or as upgrades based on an internal approval process. Companies need to design a product development process that governs most of the changes made to the products. Companies also need to be clear on what is part of product development and what is part of specification.

6.1.3 Research question #3

Is product modeling/configuration the right strategy to pursue for the timber house manufacturers?

6.1.3.1 How does product modeling go with industrialized construction

Introducing product modeling and configuration will probably be a rather lengthy journey for any company that makes that decision. Even if such an initiative might be a short-term burden it will probably generate positive long-term effects for those who try. What strategy to pursue will however depend on what products they want to sell and what sales channels to use. Firstly, companies need to be absolutely clear on what they want to accomplish, after that they can start crafting the right tools and processes for accomplishing what they have set out to do.

Companies working with consumers could engage more in the sales process to take better control of the product specification and to close the gap between themselves and the customers. Companies working with professional customers need to find ways to make their customer understand how tradeoffs from their original wishes have a positive influence on price and quality, i.e. long term wins for the customer.

6.1.3.2 Align products to business model and processes

Companies need to sit down and analyze how products, business model and process structure work together. With that analysis as a base, companies can start, either with existing product family and then build appropriate processes – or they could use that analysis to achieve better coherence between the three.

It will be easier for companies when they are clear on what products to sell and how to manufacture those products, to start aligning their processes. Fundamental work to align the business through workshops etc. will be a required start before companies can proceed.

6.1.4 Research question #4

How can companies proceed?

6.1.4.1 How to proceed

Companies aiming forward, towards product modeling will probably need to invest more into R&D. Looking at other industries and other countries reveal that much development is done in-house, not by industry common efforts.

When trying to innovate IT, companies must look further into the future than just one year, according to a McKinsey report on IT strategy, Craig et al (2007). Benefits will most likely not come at an instant; instead they have to be observed over a long period of time. So the best advice for timber house manufacturers is to be forward looking and persistent in their efforts as well as having faith in themselves and what they are trying to accomplish.

6.1.4.2 Summarizing advices

- Better define CTO and CIO roles and responsibilities
- Emphasize how the IT strategy creates business value for the company
- Adapt the sales process so that it better connects the company to the customer
- Think about how to improve processes and make them clearer and more established in the organization
- Find out what the current status of the product documentation is.
- Find a product modeling method that levels with your ambitions, be sure to include own staff to retain knowledge in the organization.
- Review the organization and how it aligns with the business model
- Reflect on where on the scale between house manufacturer and construction company you are positioned and how that affects the business model?
- Include more work in a product development process that governs most of the changes made to the products.
- Be clear on what is part of product development and what is part of specification process.
- Close the gap between company and customers in the specification process
- Consider how products, processes and business model are aligned

6.2 Risks

Pursuing configuration systems and product modeling are obviously also associated with risks. Before going into a relatively large project that will probably influence how companies work and organize themselves, they will need to do a comprehensive risk analysis. Some of the risks (but not limited to) with pursuing what has been suggested in this project are:

- Fluctuating market conditions – the construction market is strongly cyclic, which could leave companies short of money or resources to fulfill a large project.
- Major shifts in the market may overturn large investments; for example passive houses could change how houses are built.
- Economy – changes to interest rates and the economic situation will affect the customer buying power, which influence how many and what type of houses that are sold.
- Market – whether companies plan to work on a national or international market will decide what rules they have to obey. More legislation to consider will make the product even more complex to manage.
- Every company must investigate the costs and benefits of how they would like to approach configuration, before taking any investment decisions.

Every company must decide for themselves how to proceed with configuration and product modeling. Creating a strategy of their own and analyzing risks as well as benefits should be the first step for all companies.

6.3 Contribution

If pursuing configuration, industrialized timber house manufacturers need to put work into an IT strategy that integrates better with the business and that can drive business. Conclusions of this project suggest that companies need to focus on three areas:

- Systematic product documentation
- An IT strategy that supports business model and products
- Integrate their IT environment by taking action on their own

6.4 Validity and generalization

The results of this research are most valid for the timber house manufacturers because all case studies have been performed within that industry. Noticeable is that prominent companies generally tends to be less open towards their competitors as well as to researchers. Therefore the companies that chose to participate in this project may have had similar issues and may not be a completely representative sample from the timber house industry as a whole.

As for generalization, the conclusions of this project would be applicable mostly for the timber house industry or in sectors that operate at the same conditions, but the results will not be applicable for the construction sector as a whole. For industrialized construction, the advice put forward in the conclusion can act as guidance on how to approach configuration and product modeling.

To improve the project it would have helped to include companies with other profiles and business models. A wider distribution of companies would have helped to better generalize the results.

The analysis and advice put forward in this report is based on the authors knowledge and opinion, it should not be considered the only way to go forward. Every company must take informed decisions by themselves.

6.5 Further research

It would be beneficial to investigate how a configuration approach affects timber house manufactures when including the complete business system. This would be an area to explore further to help companies to make the right decisions for the future. When other considerations are included, the playing field for how to adapt configuration might change.

It would also be interesting to investigate the possibility to develop a model for measuring the benefits of product modeling and configuration.

Needs and approach for the industry have been identified in this project. The next step would be to practically implement configuration in construction as a pilot project.

There is also a need to spread knowledge of configuration in the industry to get companies to understand all the benefits. Initiate joint projects between academia and the industry, where the industry drives the project and academia brings the expertise.

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I

ICT SUPPORT FOR INDUSTRIAL PRODUCTION OF HOUSES – THE SWEDISH CASE

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ABSTRACT: The Swedish construction sector is currently undergoing great changes. The large costs for labour have forced the construction companies to rationalise and minimise labour intense work operations. Therefore, the current trend in construction to adopt the principles of lean production and transform it into lean construction, suits the Swedish way of working and the entire Swedish construction sector has caught on. A growing market is the prefabrication of building elements that are transported to site and then erected. The development has been taken so far that modular houses i.e. vol-umes/rooms are prefabricated.

Companies in the prefabrication industry within construction fall between two sectors; the construction industry and the manufacturing industry. In terms of IT support the contradiction between the two sectors become evident. Software developed for the construction sector seldom provide enough detailing to suffice as a basis for industrial production, while software supporting the manufacturing industry are incapable of delivering standard construction documentation.

The current study presents a multiple case study where six Swedish industrial manu-facturers of timber houses were studied. The process from tender acceptance to mod-ule delivery is described. Alongside, a survey of the building system revealed that much still needs to be done in terms of documenting a building system. The results show that the question of IT support is more a question of consequent information strategies than eloquent IT tools. The pressing need for a method for documenting building systems is stressed and different methods are discussed.

KEYWORDS: timber houses, industrial construction, lean construction, timber buildings.

1 INTRODUCTION

Currently the Swedish construction sector is undergoing great changes. In order to meet demands from the market the sector needs to become more efficient in several areas, quality and reliability being two of the most prominent. There is a trend to transfer methods as lean production from the successful manufacturing industry (e.g. cars) into lean construction for the construction industry, (Koskela 1992). One move towards a more industrialised approach is to prefabricate elements in factories and transport them to the building site for erection. Later years have seen an increasing degree of prefabrication and currently companies involved in modular house prefabrication foresee a strong development, (Nasereddin et al 2007). The prefabrication strategy changes construction companies from object-oriented builders to production oriented manufacturers. Unfortunately, the ICT-tools developed for the construction sector do not support an automated manufacturing, while the tools developed for the manufacturing industry lack support for structural design and detailing, (Johnsson et al 2006).

When designing buildings extensive amounts of information is generated and often time is spent searching, sharing and recreating this information, activities that can be seen as waste. Information management in building design is a key area for improvement when aiming at lean construction, since the energy put on producing drawings and specifications for each new object is out of proportion compared to the benefit, (Nasereddin et al 2007). One of the first steps towards automation is a distinct documentation of the product as a base for an information strategy, (Ford et al 1995).

This paper presents a case study of six medium-size Swedish manufacturers of prefabricated timber buildings. This paper focus on describing what properties an information strategy should have for an application in industrialised construction. The feasibility in industrialised construction of some established product modelling tools are discussed. The importance of a rational information management within the companies is identified as a success factor.

2 THEORY

Several methods for documenting product structures exist in the research community, although few have been fully implemented in the construction industry. The following chapter will present some possibilities, however alternative methods exist.

2.1 *Product modelling with CRC cards*

The purpose of CRC (Class, Responsibility, and Collaboration) cards is to document objects primarily for software programming. The concepts and modelling techniques of CRC have later been adopted (Hvam and Riis, 1999) to product modelling within the construction industry, visualising products prior to actual software programming. CRC cards are used to record objects, their behaviour, responsibilities and relationships. The CRC card method is a low-tech, easy way of documenting products, transferring knowledge from domain experts, possessing knowledge about the product, to system developers who perform the actual programming. The method defines, besides the CRC cards, different phases where objects are identified, structured, understood and documented in a product model. CRC cards can also fulfil a purpose once the software is implemented supporting maintenance and further product development.

The CRC card, fig. 1 is used for interpretation of the physical product into programming code, a configuration software. For various purposes different views of the product model are created. Sales, design and manufacturing preparation etc. have different information needs and therefore various viewports are established, in compliance with Gross (1996). A general sketch of the hierarchical product structure must be presented in addition to the CRC cards, establishing the relationships between the parts. Together they present enough information to construct a configuration tool.

Implementation of configuration software is described by Haug and Hvam (2006) in steps where CRC cards constitute one phase. Implementing configuration tools is a process that involves far more than the technical description of the product, however it is an important step. The following seven steps are suggested (Haug and Hvam, 2006):

1. The processes in which product specification is made are mapped out. There has to be an understanding of what the configuration tool are to support.
2. Product analysis, existing product ranges are analysed.
3. Object oriented analysis, results in a specification of requirements for the product structure
4. Object oriented design of configuration software. The analysis model created in step 3 is adapted to the configuration software.
5. Programming. Existing software is adapted or new software is developed. The CRC cards are used when programming the system with objects and rules.
6. Implementation of the completed configuration software and future specification process.
7. Maintenance and further development

If using CRC cards for maintenance and product development it is an advantage if they are handled digitally, eventually integrated with the code in the configuration software. In this way changes in rules can be made in the system and the software can tell which cards are affected by the changes, or even update them automatically.

Object no.	Object name	Date	Author
Object mission:			
Superparts:		Superclass:	
Subparts:		Subclass:	
Sketch:			
Responsibilities			Collaborations
Object knows			
Object does			

Figure 1. CRC Card (Hvam and Riis, 1999).

2.2 *Product family modelling*

Most implementations of product modelling regarding construction are primarily oriented towards establishing a Building Information Model (BIM) and general information modelling of the traditional building process.

A theory based on mass customization (MC) is described by Jørgensen and Petersen (2005), where product fundamentals for being applicable to product configuration are listed. A series of product variants building up a product model is described. Applied to buildings, a product model could be represented by a family of houses all originating from the same design. The product model must fulfil not only the purpose of describing all modules included, but also the rules for how they relate to each other. One important aspect brought up by Jørgensen and Petersen (2005) is that most methods for product configuration are focused on modelling the geometrical solution space of a configuration process. It often describes possible choices and how to build actual product structures, whereas it is just as important to include information concerning customer, logistics etc. Information can typically be prices, stock etc.

Jørgensen and Petersen (2005) also bring up the aspects of modular properties, which are connected to customer requirements. Customers do not need to specify the technical solution; instead a range of product properties is chosen which corresponds to a certain combination of modules and components, fig. 2. The technical specification can be handled by technical staff or a salesperson instead of the customer.

According to Jørgensen (2005) "*a model can serve as a foundation for the configuration process because it has a set of open specifications, which has to be decided to determine or configure an individual product in the family*". In construction the amount of open specifications tend to be massive. Therefore it is fundamental that detail and context of the model is set in a way that facilitates the specification process as much as possible. The easiest way of product configuration is selecting a set of pre-defined modules, assuming it is unnecessary to adjust or construct new modules. However, if modules have to be modified or added, the configuration tools must be constructed accordingly.

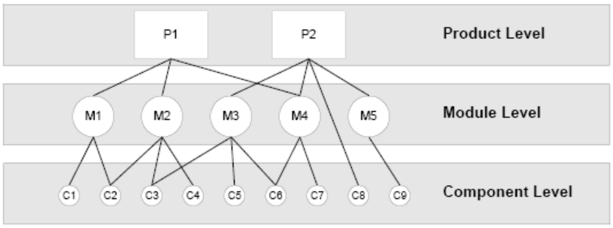

Figure 2. Combining components to modules and products, (Jørgensen 2005).

Product development using a product family modelling approach has to apply the modular design concept. New products and modules must be developed for modular design. Also it is vital that the company not only defines implementation of a configuration tool as an ICT-project (Jørgensen 2005). Besides understanding the ICT-tools it is essential to gain knowledge of the product range, business processes, and organisation and markets demands in order to succeed with a configuration system. This is not just a question of choosing the best ICT-tool on the market.

The benefits of using configuration systems have been explored in Denmark and Finland by Jørgensen (2005) and Männisto et al. (1998) respectively:

Männisto et al. (1998)

- Ability to fulfil a wide range of customer requirements
- Shorter lead times in the sales-delivery process
- Increased control of the production
- Reduction in customer-specific design
- Efficient way to offer a broad product line
- Improved quality

Jørgensen (2005)

- Establish a link between the sales department and the production
- Secure fully specified orders
- Secure valid product documentation
- Easier to deal with large number of variants
- Less maintenance of production documentation
- A tool for proactive sales

Both research groups find increased quality and control as the main benefits, which is exactly what industrialised construction is about.

2.3 *IFC for the construction industry*

IAI (International Alliance for Interoperability) has taken on the challenge to standardize information exchange in the building sector through launching Industry Foundation Classes (IFC). The IFC standard is an object oriented data model for the building industry and facilities management. Within the IFC model, geometry, building component properties, costs etc. can be incorporated. Information can be made interpretable by virtually any application that works with structured data handling of AEC building projects, (Froese 2002). IFC models are intended to work as a neutral information exchange format. IFC development work is based on the EXPRESS data definition language that is part of the STEP standard.

Rönneblad and Olofsson (2003) developed and implemented IFC models for precast concrete elements in the expert system IMPACT, an application used to design precast concrete elements with automatic generation of drawings. IMPACT functions as a manufacturing preparation tool and imports the architectural model with windows, openings etc. The precast designer then uses the geometry created by the architect to model precast concrete elements. The refined model was then exported to the IFC model server attributed with BSAB classification codes. (BSAB is a Swedish industry standard for labelling and classification of building object). The BSAB code is later used for extraction of data to estimation and scheduling software. The information transfer through IFC was not complete e.g. information about cast in material was lost in the export due to lack of support for precast elements in IFC 2.0.

Conclusions on IFC drawn by Rönneblad and Olofsson (2003) coincides with Ekholm et al (2000), who states that "The main criticism that can be addressed to IFC is the prominent lack of an expressed basic philosophy and pedagogical descriptions related to practical needs". In reality this means that the same type of problem is not solved consistently throughout the different parts of the IFC standard. There is also an underlying criticism towards the top-down approach of the implementation of the standard, not connecting to practical needs.

According to Froese (2002) significant portions of IFC is currently a mature and stable standard, however work still remains in specific areas. Efforts have been made to develop IFC, e.g. for precast concrete elements and structural timber, both of which are partly included in the latest release IFC 2x3. The work in structural timber is still ongoing and has the goal of supporting automatic exchange of data between computer systems from design through to automated manufacturing.

2.4 *The information engineering method*

A comprehensive introduction to the information engineering method (IEM) is given by Martin (1986). It builds on a gradual increase of level of detail, from abstraction to physical facts. The process is facilitated by the Information Engineering Facility (IEF) Computer Aided Software Engineering (CASE) tool. The main strength of IEM is that it connects the information strategy to the industrial goals of the company. IEM is realised in seven steps:

1. Information Strategy Planning
2. Business Area Analysis
3. Business Systems Design
4. Technical Design
5. Construction
6. Transition
7. Production

The CASE tool is similar to a CAD tool, but for software development and produces graphical representations of processes. The distinction between data modelling, activity modelling and product modelling is made clear. These three areas have their own special tools, where product modelling e.g. can be realised through IFC and activity modelling through IDEF0. The feasibility of the information engineering method in the construction sector was tested by Ford et al (1995). Findings were that IEM is useful on a strategic level, but must be completed with object-oriented methods when reaching more detailed levels.

3 CASE STUDY

The case study involved six companies with a clear prefabrication strategy. The companies are medium-sized, approximately 100 employees, with around 20% of the staff working with design and administration and the remaining engaged in production. All six companies use timber for the load-bearing structure, a heritage from the dominant position of timber on the Swedish market for single-family dwellings. Five of the companies have chosen to manufacture modular houses inside a factory, reducing the building site to mere montage, fig. 3. The volume elements are finalised with claddings and HVAC installations, which are connected on site. Buildings using the modular technique can be up to five stories high. The sixth company produces flat elements (walls and floors) and mounts them on site.

Two of the companies sell directly to private customers, while four of them work with professional customers who in turn sublet dwellings or public premises. Two of those companies work mainly with public premises, such as schools and prisons. They are forced to follow drawings and specifications made by a third party consultant under the restriction of the Government Procurement Agreement (GPA) and compete with traditional construction firms on the open market.

Organisation in the studied companies is often clear, however not process oriented in any formal way. Building projects follow predefined paths, which involve multiple departments. There is no clear process orientation or process leader, which can create complications in cooperation between departments. The ownership of improvements concerning multiple departments or product development does not seem to have an appointed function. Theoretically the companies have all the prerequisites to control both the processes and the resources used, but in reality an organisation focusing on streamlining the production has not yet been established, which is consistent with the findings of Nasereddin et al (2007).

All companies were visited and studied at their production plants, interviewing employees from all departments from sales to production to screen the process. Drawings were studied to describe the documentation of the building system. Questions were also posed on the information strategy and its implementation.

Figure 3. Modular house production.

3.1 *The sales process*

The two companies working directly with private persons as customers use sales agents spread out through Sweden as the communicator of the building system. The sales agent works with an extranet, where information regarding the product range, including choices of material and prices etc. have been posted. The company itself remains idle until a contract between the customer and the company has been signed. Detailing is then decided iteratively, through communication between the design department and the sales agent.

This is a process that generates much information in form of documents, emails etc. and there is no system for managing this data. The finalised product specification is gathered in a manufacturing order, which follows the product through manufacturing. The manufacturing order is the main document where specifications are recorded, but there is no ICT tool coupled to its conception or refinement, it remains a written paper throughout. When the process of product specification has come to so much detail that an application of a building permit can be submitted, drawings are made by the design department at the company.

The four companies working with professional customers do not use sales agents, but have skilled salespersons in-house, whose main task is to establish good relations with customers and satisfy all their requirements. The salesperson must have good knowledge of the building system, good conception of costs and constantly be aware of the order stock to present a correct product offer to the customer. Two of these companies work mainly with design-and-build contracts, controlling design, specification, manufacturing and erection in-house. The two others work with public premises, under the restriction of the Government Procurement Agreement (GPA). This means that the companies have limited possibilities to change specifications in the tender, which leads to inefficient design for industrialised manufacturing.

3.2 *The design process*

The two companies working with sales agents use standard type houses as templates for the production of drawings. The standardisation has inspired these two companies to invest in ERP-systems (Enterprise Resource Planning) for economical follow-up and material and resource planning (MRP). Unfortunately, the CAD software and the ERP system does not communicate with each other, resulting in the product (the building) being defined in two different ways, not seldom with discrepancies. Standard CAD software for construction is used to produce drawings printed on paper. Bill of materials is produced as quantity take-off directly from drawings and listed in Excel (no link between CAD and Excel for this purpose). The specifications needed for manufacturing are listed using Excel or Word.

The four companies working on the open market with professional customers cannot use standard type houses, since the customer defines the main characteristics of the building. Standardisation is instead sought in the manufacturing process, by defining standard joints, standard stairwells, standard wall and floor sections etc. Since the layout of the building affects the manufacturing to a large extent, strategic alliances with architects and customers are sought to streamline the design process. Building design is performed in two stages; first the architectural design that defines the building envelope and divides it into modules suitable for manufacturing; secondly the detailed design where the elements building up each module is documented on manufacturing drawings. HVAC installations are also designed twice; on a building level and on an element level, in some cases by in-house consultants and in some by external ones. Standard CAD software for construction is used to produce drawings printed on paper. Bill of materials is produced as quantity take-off directly from drawings and listed in Excel (no link between CAD and Excel for this purpose). The written specifications needed for manufacturing are listed using Excel or Word. Ordering of materials is made based on the bill of materials as a manual action.

3.3 *The manufacturing process*

The design process results in a bunch of manufacturing drawings and lists, which are used as steering documents for manufacturing. None of the studied companies have automated their production plants, but plans exist in several of them. Work is based on craftsmanship with hand-held tools. The factory seems to work as a stand-alone production unit and the drawings produced have a strong resemblance to those used for on-site construction.

The capacity of the production plants vary, on the average 150 m^2 finished volume elements are produced each day. The degree of prefabrication is taken as far as possible; the finished volumes contain fully equipped kitchens, finalised bathrooms and all interior claddings. Only components at risk for theft are delivered directly to the building site.

3.4 *Building system documentation*

The results of the study show that the technical platforms, i.e. the building systems, very much build on the same principles. The degree of prefabrication is what differs between the companies. Parts can be categorized in two main groups of information – detail and type solutions. Detail solutions describe meetings between components for example a joint between two wall segments. Detail solutions can also encompass specific methods for e.g. mounting kitchen assemblies. Type solutions describe general solutions for elements with a cross section, e.g. walls and floors, but not their geometrical extent, only the layer constitution.

Rules regarding assembly and limitations of the technical platform are not consistently described. They exist on different levels in the organisation and are not documented with a consistent method. Many of these rules have not been documented at all and exist only in the mind of the employees. The rules affect the modularisation in the design process, which is one of the reasons why they must be documented methodically.

Type and detail solutions are documented in a drawing archive at the studied companies. These drawing archives often lack possibilities for attributing search tags, which makes it difficult to find specific information. No specific person is assigned the function of managing the building system. This means that product development is not a separate process within the companies, but rather an activity that arises in project after project. Therefore, the change of the building system over time is not traceable. There is a risk for reinvention of already used solutions, but more severely the non-existent product development process prevents the use of modularisation strategies and consistent handling of rules for the building system.

3.5 *ICT tools*

All of the companies work with a range of ICT tools to support their production. However, the linkage between the ICT tools is poor, leading to information loss and iterative recalculations of the same data. Two of the studied companies use ERP systems to keep track of the material flow, material orders and stock take-off. The ERP system and the CAD software do not use the same data exchange format c.f. The Design Process above. The communication problem between the systems arises since the CAD software stems from the construction industry, while the ERP system is developed for the manufacturing industry – differing data formats and database technology hinders the information flow. So why cannot the companies exchange one of the systems? If deciding to use a CAD software from outside construction, all templates and symbols needs to be redefined. Furthermore, suppliers of materials (e.g. windows) also supply CAD-symbols ready-for-use predominantly in AutoCad format. ERP systems developed directly for the construction sector seem non-existent. General time plans for the project from the ERP system are enhanced and revised in other ICT tools at each department in the company. Apart from the larger systems, individual solutions with Excel and VB-scripts are extensively used to automate smaller subtasks. The data is not migrated into any receiving system.

The four companies that do not use ERP systems instead have problems with information management. It is clear that the process focus has not yet reached the design process. Information is dependent on individuals and the lack of an overall process management is prominent. There is no central management system that controls the progress of the process; therefore it is difficult for individuals to keep track of the progress. Projects are defined in the early stages through CAD-drawings and PDF documents with specifications. CAD data is seldom re-used in the following detailed design, merely as print-outs. Bill of materials are not produced with CAD data as the basis, but are Excel lists enhanced with a VB-script to automate the process. Scheduling for manufacturing is done by the plant manager who also controls the supply of materials. The work is manual with standard tools (Excel, MS Project).

4 ANALYSIS AND DISCUSSION

First of all, industrialised construction is a mixture of two worlds. To stay competitive on the market, these companies need to stay compatible with the tools available in their field (templates from suppliers, common estimation data) and also deliver data that is accepted by the customer (relational documents in the correct format). Any deviation from this route creates immediate problems, increasing in-house administration, which is exactly what these companies try to avoid. On the other hand, an industrialised process is sought, to improve quality and control. Industrialisation is not supported by common ICT tools for construction, therefore companies want to learn from the manufacturing industry and attempts have been made to incorporate tools such as ERP systems. Once again, the link to established construction software is missing, increasing in-house administration.

This is seemingly a problem that could be overcome by using a neutral exchange format such as IFC or STEP. The only problem is that IFC is developed for the construction sector and STEP for the manufacturing industry. Suppliers of ICT tools have the same specialisation in sectors and tend to support one of the formats, not the other. Traditionally, the level of detail in modelling software in the construction sector is poor (e.g. studs are usually represented as belonging to a layer and nails are not even incorporated). As preparation tools for manufacturing, common CAD tools do not perform well. A complete model including details as nails might on the other hand be too heavy to work with. Modularised ICT tools would serve well. Today, there are some tools that have the potential of filling this gap, but their main drawback is that the support for HVAC installations is non-existent. The strategy for a single company is individual and at this moment, there is no common clear working method that is recommendable or reliable.

If the aim is to industrialise production it is painfully clear that the companies must learn to document their own product. All automation relies on well-documented products including the connection between the product modules. All of the studied companies can easily document their product structure in terms of what building parts their system consists of and how they are built up in detail. This type of information is well communicated today. Even working methods for detailing are documented e.g. specifying nailing distances or mounting instructions for windows. What is missing is a systematic approach to describing and realising the connections between building parts, such as Product Family Modelling. According to Hvam and Riis (1999) experiences from a number of Danish companies show that the implementation of product models done without a proper method or modelling technique often resulted in an unstructured and undocumented system, which made it very difficult or nearly impossible to maintain and develop the product model further. An alternative to product family modelling could be the information engineering method using the IEF CASE tool, Ford et al. (1996).

In the IFC standard, the connection between parts is represented by a direct parent-child relation. IFC have mostly been used in the traditional construction process, facilitating communication with model based CAD. However, the authors would like to raise the question if it is possible to use IFC as a foundation for building generic product structures, instead of just documenting existing instances. In the case study presented, companies will have to build product structures that can serve as a product model for customer adapted instances. Eventually, IFC could be used as this generic product structure. The idea was tested in Ekholm et al (2000) with discouraging results. In the industrial production of timber houses companies control far more of the value-chain and thus chances of success are greater. A strong factor against the approach is the companies' lack of understanding for the benefits of a standardised product model and the efforts needed to establish it. Männisto et al. (1998) further claims that "*STEP is fundamentally based on a fixed standardized product schema that cannot be extended for the purposes of a company. In our view, this seriously limits the potential of STEP when companies start utilizing more advanced product modelling concepts*." The same statement should hold true also for IFC as it is based on the STEP standard.

CRC cards on the other hand, are more focused on relations between parts and might be a good working method for a company in the documentation of their current building system. The question is whether it is good strategy or not to pursue CRC cards and move on to the development of a configuration system? Jørgensen (2005) and Männisto et al. (1998) both claim better conditions for industrialisation using configuration systems in terms of quality control and process orientation. Still, the development of a configuration system for the industrialised construction sector needs to stay compatible with the construction sector in general, different from the approach in Gross (1996). The configuration system needs to offer a support for manufacturability without becoming yet another administrative burden. This calls for a development where both the working methods and the tool itself are taken into account, providing a possibility to simultaneously improve internal work processes and ICT support.

The actual product definition within the studied companies seems to be debated. Administration claims that the product is defined already in the ERP system fed from the manufacturing order. The structural designer does not agree, since detailing is never done in the early stages, and instead claims that the CAD software defines the product. Follow-up using the ERP system is then difficult to perform since the data created in CAD cannot migrate back to the ERP system automatically. The work flow with interacting product data and economic management is common in the manufacturing industry, where work flows and information paths generally are better documented, (Johnsson et al. 2006). This is a need that must be addressed in the future, both by companies deciding on an information strategy and by ICT developers providing reliable solutions. Once again, a good documentation of the information flow within companies is the first step towards a strategy, (Ford et al, 1996). The process, the ICT tools and the building system are tightly linked to each other, which means that improvements must address them simultaneously in a context, not separate from one another.

5 CONCLUSIONS

This paper has identified the need for well-documented building systems at companies striving to industrialise their production. Methods to achieve a description exist, but generally there is a lack of methods describing connections between modules in a consistent manner. To achieve a reliable description of a building system a combination of methods is proposed. CRC cards can be used for screening and mapping the building system, (Hvam and Riis 1999). To take control of the manufacturability, a configuration system is useful. The core of the configuration system could possibly be based on the IFC standard, opening up a path for neutral communication between ICT tools. The key point to succeed with ICT and industrialisation is to recognise the dependency between the development of working methods and ICT tools. This could be addressed with the information engineering method as an umbrella, (Ford et al. 1996). Companies wanting to develop in this direction cannot wait until ready ICT solutions are at hand, and ICT suppliers need to truly understand what industrialised construction is about.

5.1 *Future work*

There is a gap between the developed, large standards for information exchange and the true needs of smaller companies. There is room for a condensation of methods, narrowing down to sector specific problems, in order to support industrialisation. This might eventually lead to a reformulation of existing methods and standards. The near future goal of this ongoing project is to make a documentation of a building system, with the aim of establishing a configuration system for industrialised construction. This will present a good evaluation test for the applicability of existing standards for industrialised construction.

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INFORMATION MANAGEMENT IN INDUSTRIAL HOUSING DESIGN AND MANUFACTURE

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SUMMARY: *Industrialized production of building components, or entire houses, reduces activities at the construction site to the assembly of parts and has the potential to increase productivity and reduce the design effort invested in every project. However, in order to realize all of the potential efficiency gains that use of predefined components could deliver effective, interoperable information management systems are required. This article presents a multiple case study investigating the processes, products and ICT environment involved in industrialized house construction from an information management perspective, focusing on six Swedish companies that manufacture timber frame elements and one that makes precast concrete elements. The aim of the study was to identify critical aspects of information management related to industrialization in the sector. The findings show that companies aiming to enhance control and productivity by improving information management need a better understanding of the requisites for efficient industrialized construction in terms of ICT support. Changes in the perspectives of the construction companies appear to be needed in terms of not only the manufacturing processes, but also information management. Three main areas are identified that should be prioritized before any investments in ICT can be implemented effectively: formal description of the relevant processes, detailed description of the product range and its full variety, and creation of an appropriate information systems strategy.*

KEYWORDS: *Timber frame houses, precast concrete elements, industrialized construction, information management, building product model*

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1. INTRODUCTION

Several modular house companies are currently manufacturing complete volumes/elements off-site in Sweden. Use of the prefabrication strategy changes construction companies from project-oriented building contractors to production-oriented manufacturers. Unfortunately, however, information management within the companies has not developed at the same pace, and documentation of their projects in many respects still resembles that of on-site construction projects.

The building design process generates large amounts of information, and time is often wasted searching for, sharing and recreating information. One reason for this is the lack of interoperability between software used in the various stages of the building process. Gallaher et al. (2004) estimated that the annual cost of inadequate interoperability in U.S. capital facilities amounts to as much as $15.8 billion. Therefore, information management in building design is a key area for improvement in attempts to improve the efficiency of the construction process (Nasereddin et al, 2007).

The study presented here identifies problems related specifically to information management in industrialized house design and manufacture – which are likely to impede overall growth in productivity and the exploitation of economies of scale in the sector – and considers their underlying causes. We believe that more refined information management systems and the use of product models could serve the same purposes in the industrial prefabrication of construction units as in manufacturing industries, i.e. facilitate the timely and efficient use of information, reduce lead times and costs of processes such as product specification, and tighten quality control.

2. FUTURE PERSPECTIVES FOR INFORMATION MANAGEMENT IN INDUSTRIALIZED CONSTRUCTION

Tailoring ICT support presents a strategic opportunity for optimizing information management in industrialized construction, and hence reducing the inefficiencies highlighted by Gallaher et al. (2004) and Nasereddin et al. (2007). Furthermore, as noted by Björnsson (2003), use of an apt information system (IS) strategy – i.e. set of information resources organized for the collection, storage, processing, maintenance, use, sharing, dissemination, disposition, display and/or transmission of information (CNSS, 2006) – provides valuable support for a company's business strategy. Thus, appropriate IT infrastructure and services, as illustrated in Fig. 1, are required.

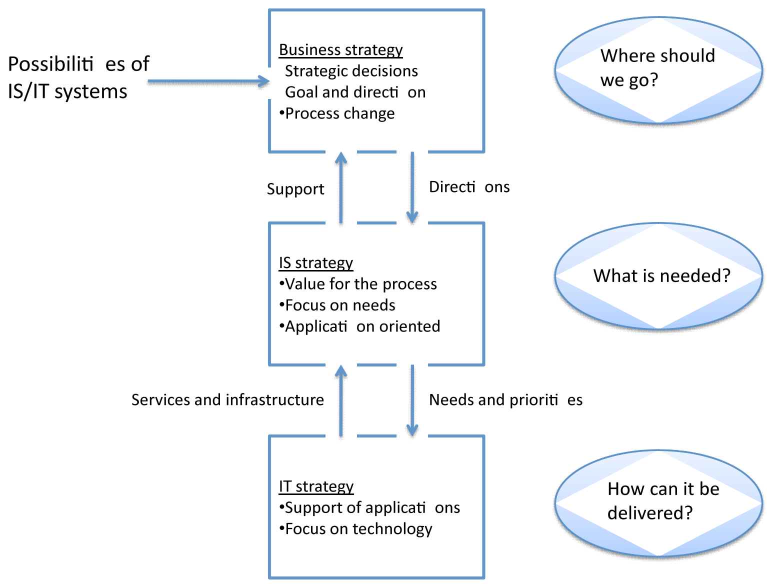

FIG 1: Information system. Adapted from Björnsson (2003).

This paper focuses on components of a company's information system that describe its products, rather than the overall system. In a computer-based information system, formal descriptions of products (ideally designed and specified using compatible digital tools) can be stored in product data models. In the literature there are numerous definitions of such models, e.g. one by Shaw (1989), and specifically regarding product models for the building and construction sector the following definition by Björk (1995)…"A type of conceptual schema where the universe of discourse consists of buildings throughout their design, construction, operation and maintenance. A building product data model models the spaces and physical components of a building directly and not indirectly by modeling the information content of traditional documents used for building descriptions."

It could be established that a product model incorporates a formal and structured definition of product information of a manufactured artifact. Further on, the product data model is described in a conceptual schema expressed in an information modeling language. The procedure for defining a building product data model usually starts with activities to capture the domain knowledge of a certain business or engineering process. This procedure, referred to as product modeling, generally involve collaborative efforts between domain experts and product modeling experts (Lee et al, 2007). An essential starting point is to establish specific purposes or objectives for the model, in order to identify the types of information that should be included (especially since construction products often contain large numbers of diverse components, thus if the purpose of the model is not clearly established at the outset the resulting model is likely to become unnecessarily complex).

In the building construction industry the term Building Information Modeling (BIM) is sometimes used, rather than product modeling, to describe the processes of generating and managing data during the entire life cycle of a building (Lee 2006). Hence, according to Succar (2009), BIM can be regarded as a methodology to manage product data throughout a building's life-cycle consisting of a set of interacting policies, processes and technologies. Smith (2008) states that "A basic premise of Building Information Modeling is collaboration by different stakeholders at different phases of the life-cycle of a facility to insert, extract, update or modify information in the Model to support and reflect the roles of that stakeholder".

A formal method that can be used to describe a product, and to define and conveniently reuse information required throughout the knowledge capturing and product modeling phases is the Georgia Tech Process to Product Modeling (GTPPM 2008; Lee et al. 2007). GTPPM is divided into several steps from acquiring domain knowledge to implementing a product model. Two of the phases are Requirements Collection and Modeling (RCM), including process modeling and specification of product information, and Logical Product Modeling (LPM). The RCM phase is equivalent to general process modeling, a key objective of which is to establish the processes that will be used to manufacture the product. Various approaches can be applied to meet this objective, and various commercial tools can be used, *inter alia* Flowchart, UML and IDEF0 (Lee et al, 2007). Process modeling essentially provides a way of understanding the process, which will be subsequently supported by the product model. In addition, the RCM phase includes the capture of product information used in the process, which can be described in the terminology used by the specific company.

The Center for Product Modeling (CPM)[1] has developed a method for designing and implementing product models to support product configuration processes. By including knowledge regarding various aspects of the product, information can be made more accessible throughout the company. The method developed by Hvam et al. (2000) includes the following seven steps:

- Mapping the processes of product specification.
- Product analysis, in which existing product ranges are analyzed. Product knowledge and product-related knowledge are identified and structured.
- Object-oriented analysis, which results in specification of requirements for the product structure.
- Object-oriented design of configuration software.
- Programming
- Implementation of the completed configuration
- Maintenance and further development

The product modeling methods mentioned above include both process and product analysis phases as a way to capture the domain knowledge, thus process and product documentation is important in any kind of product modeling effort. The product modeling methods mentioned above include both process and product analysis phases, and are cited to illustrate the importance of capturing relevant domain knowledge using interoperable systems, and thus the importance of appropriate process and product documentation in any kind of product modeling effort.

A term used by the CPM in its literature is "product range", which is used in the same sense as the term "product architecture", defined by the *Product Development and Management Association* Glossary for New Product Development as "*the way in which the functional elements are assigned to the physical chunks of a product and the way in which those physical chunks interact to perform the overall function of the product".* According to Smith (2007), there are two main types of product architecture: modular and integral. Modular architectures have high degrees of flexibility in product development and manufacture, each "chunk" incorporates one or a few functional elements and the interactions between them are well defined. In contrast, integral architectures have high degrees of stability and optimization, overall functions of the products are satisfied using more than one chunk, but each chunk incorporates many functional elements, and the interactions between chunks are ill-defined. However, modularity is a relative property (Ulrich and Eppinger, 2008), i.e. a product is rarely strictly

[1] CPM (Center for Product Modeling). The Association for Product Modeling, Denmark. Available from: <http://www.productmodels.org>, [Accessed: 4 June 2008].

modular or integral, instead products generally have varying degrees of both modularity and integrity in their architecture.

3. METHOD

This article is based on a multiple case study investigating processes, the ICT environment and product documentation in seven industrialized construction companies with the intention to elucidate the current status of information management in the sector, ways in which information is used throughout their processes and the requirements for adopting a product model approach. Current information management strategies were investigated, in terms of process and product documentation.

The case study material was gathered mainly through interviews with 3-4 key employees of each company, at their respective workplaces, involved in activities ranging from sales to manufacturing. Together with the subjects, the process from sales to manufacturing and assembly in their respective companies was mapped out, either on a whiteboard or using post-IT notes to minimize the risk for misinterpreting communications. The results were later transferred to IDEF0 process maps. In the same sessions information flows were also discussed to acquire an understanding of the information related to the various steps of the process. It should be noted that the two IDEF0 diagrams presented in the article were prepared by two different researchers. To obtain a complete overview of the ways in which information was processed and transferred in the companies, each company's Chief Information Officer was contacted to verify our model of their ICT systems. The information acquired was formalized in schemas. Additional information and various documents were gathered at the time of the visits to obtain an understanding of the companies' product ranges and product documentation strategy.

4. CASE STUDY

4.1 Brief introduction to the companies

Relevant information on the companies included in the case study (excluding their names for reasons of confidentiality) is summarized in Table 1.

Table 1: A brief introduction to the companies

Company	Architectural and Detailed Design	HVAC Drafting	Manufacturing
Volume module producer 1	• Interface from sales: text documents, master time plan from separate software, calculations for offer from separate software • Arch. Design: 2D AutoCad • Detailed design: second CAD-system • Bill of materials in spreadsheet	• Interface HVAC: import and export in Auto-Cad format. Occasionally paper drawings for detailed design. • Made by external resources in Auto-Cad format	• Interface Manufacturing: printed drawings, data from second CAD-system feeds wall production, manual quantity take-off from drawings. • Manual work apart from wall production • Written documentation and printed drawings.
Volume module producer 2	• Interface from sales: text documents, master time plan from separate software, calculations for offer from separate software • Arch. Design and detailed design: 3D AutoCad format • Bill of materials in spreadsheet	• Interface HVAC: import and export in Auto-Cad format. • Made by internal resources in Auto-Cad format	• Interface Manufacturing: printed drawings, manual quantity take-off from drawings. • Manual work • Written documentation and printed drawings.
Volume module producer 3	• Interface from sales: text documents, master time plan from separate software, calculations for offer from separate software • Arch. Design and detailed design: 3D AutoCad format • Bill of materials and time planning made in a calculation system	• Interface HVAC: import and **export** in Auto-Cad format. • Made by internal resources in Auto-Cad format	• Interface Manufacturing: Written Printed drawings. Manual quantity take-off from drawings. • Manual work • Written documentation and printed drawings.
Volume module producer 4	• Interface from sales: text documents, master time plan from separate software, calculations for offer from separate software • Arch. Design and detailed design: CAD-system DDS • Bill of materials and time planning made in spreadsheet	• Interface HVAC: Import and ex-port in Auto-Cad format. • Made by external consultant in AutoCad format	• Interface Manufacturing: Printed drawings. Manual quantity take-off from drawings. • Manual work • Written documentation and printed drawings

Volume module producer 5 (single homes)	• Interface from sales: sales support system coupled to the ERP system, customer specifications transferred • Arch. design made by external architect or in-house in 3D AutoCad format • Detailed design in the same CAD-system. Bill of materials and time planning made in an ERP system	• Not necessary, single-family homes seldom have complex HVAC technology	• Interface Manufacturing: Printed drawings. Automatic quantity take-off from ERP system. • Manual work • Written documentation and printed drawings
Element producer 1	• Interface from sales: sales support system coupled to the ERP system, customer specifications transferred • Arch. design made by external architect or in-house in 3D AutoCad format. Detailed design in the same CAD-system • Bill of materials and time planning made in an ERP system.	• Not necessary, single-family homes seldom have complex HVAC technology	• Interface Manufacturing: Printed drawings. Automatic quantity take-off from ERP system. • Manual work • Written documentation and printed drawings
Element producer 2	• Interface from sales: master time plan, quantities and cost estimations in Excel spreadsheets • Design and specifications are produced in **CAD-system** and product data including bill of materials are managed in a database	• Not necessary, since the producer only manufactures filigree floors and double walls	• Interface Manufacturing: NC data generated machine files • Highly automated production line • Control and monitoring, lift instruction, quality control reports, marking labels and marking labels through UniCAM

4.2 Timber frame houses

Six of the companies examined in this multiple case study construct timber frame housing using prefabrication strategies. The companies are medium-sized, each with approximately 100 employees, ca. 20 of whom are involved in design and administration, while the others are engaged in production. Five of the companies have chosen to manufacture factory-built modular houses, reducing activities at the building site to mere assembly, Fig. 2. The volume elements are prefabricated with claddings and HVAC installations, which are connected on site. The sixth company produces wall and floor panels that are assembled on-site.

FIG 2: Modular house production

The organization in the studied companies is often clear, not process-oriented in any formal way. Building projects follow predefined paths, which involve multiple departments. Theoretically, the companies have all the essential tools to control both the processes and the resources used but, in accordance with the findings of Nasereddin et al. (2007) they have not yet established an organization tailored for streamlining production.'

4.2.1 Process Model

Two of the companies deliver directly to private persons, and use sales agents spread throughout Sweden as communicators of the building system. The sales agents use an extranet, which provides them with information regarding the product range, including available materials and prices etc. The production facilities remain idle until a contract between a customer and the company has been signed. Detailed specifications are then decided iteratively through communications between the design department and the sales agent, as shown in the IDEF0 lower-level (A2) child diagram presented in Fig 3, which provides details of the design phase in the overall process from the sale to the manufacture of modular houses outlined in a parent diagram (A0, not shown).

The sales process generates large amounts of informal data in the form of documents, emails etc., but currently there is no system for managing this information. The finalized product specifications are gathered in a manufacturing order, which follows the product through manufacturing. The manufacturing order is the main document in which specifications are recorded, but there is no ICT-tool coupled to its conception or refinement; it remains written on paper throughout the manufacturing process.

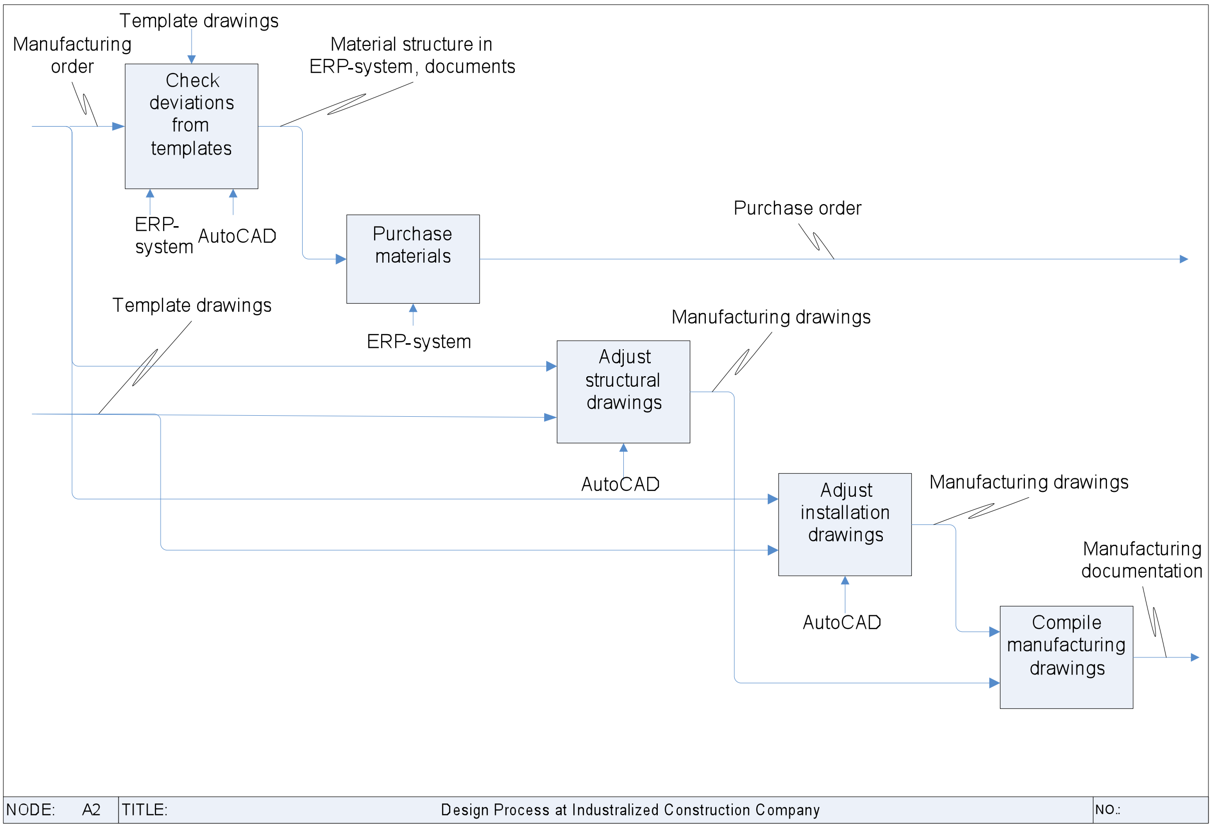

FIG 3: Extract (IDEF0 A2 child diagram) of the design phase from a process model at a Swedish company manufacturing modular houses

The other four timber frame companies operate in the open market with professional customers, and hence cannot use standard types of houses since the customers define the main characteristics of the buildings they require. Standardization is instead sought in the manufacturing process, by defining standard joints, stairwells, wall and floor sections etc. Since the layout of each building strongly influences its manufacture, strategic alliances with architects and customers are sought to streamline the design process. Each building is designed in two stages: first an architectural design is drafted that defines the building envelope and divides it into volumes suitable for manufacture, then a detailed design is prepared in which the elements contributing to each volume are documented in manufacturing drawings. HVAC installations are also designed in a two-step process, at a building level and at an element level, in some cases by in-house consultants and in others by external consultants.

The design process results in manufacturing drawings and bills of materials, which are used to control the manufacturing process. None of the studied companies have automated their production plants, but several are planning to do so. Work is based on craftsmanship with handheld tools. At each case company the factory seems to operate as a standalone production unit and the drawings produced have strong resemblance to those used for on-site construction. The capacities of the production plants vary, but on average 150 m^2 finished volume elements are produced per day at each plant. The degree of prefabrication may be very high; finished volumes may contain fully equipped kitchens, finalized bathrooms and all interior claddings.

4.2.2 ICT Models

All of the companies use a range of ICT tools to support their production. However, the links between their ICT tools are poor, leading to loss of information and iterative recalculations of the same data. Two of the companies use Enterprise Recourse Planning (ERP) systems to keep track of the material flow, material orders and stock take-off. However, their ERP system and CAD software do not use the same data structures or compatible database programs (see section 4.2.1 above), which severely hinders the information flow between the systems, because the CAD software stems from the construction industry, while ERP-systems are not developed specifically for construction. In addition, from the larger systems, individual solutions with Excel and VB-scripts are extensively used to automate smaller sub-tasks. The data are not migrated into any receiving system.

The four companies that do not use ERP-systems instead have problems with information management, and insufficient attention has clearly been focused on optimizing and integrating the design phase of the process to date. There is no central management system to control progress during the process, so it is difficult for individuals to keep track of the progress. Commissioned buildings are defined in early stages in CAD drawings and PDF documents with specifications, but the CAD data are seldom re-used in the following detailed design phase, they are merely used as printouts. Bills of materials are not based on CAD data either, but are compiled in the form of Excel lists enhanced with a Visual Basic script to automate the process.

4.2.3 Product Range Documentation

The findings of the study show that the technical platforms, i.e. the building systems, are very similar in many respects, the main differences between them are in the degree of prefabrication. Further, the parts they use can be categorized and described in two main groups of information – detail and type solutions. Detail solutions describe connections between components, e.g. a joint between two wall segments and may also encompass specific methods, e.g. for mounting kitchen assemblies. Type solutions describe general solutions for elements with a cross section, e.g. walls and floors, but they do not describe their geometry and dimensions, only the constitution of the layers.

Rules regarding the assembly and limitations of the technical platform are not consistently formulated, and they are not built into the CAD software. Instead, the rules originate at various levels in the organization and are not documented by a consistent method; in fact many of these rules have not been documented at all and exist only in the minds of the employees. Thus, there are few restrictions preventing designers creating designs that do not align with the building system, and in order to optimize the overall process systematically followed rules should be incorporated in the building breakdown structure from the start of the design phase onwards.

Type and detail solutions are documented in drawing archives, which often lack facilities for assigning search tags, which makes it difficult to find specific information. Furthermore, no specific person is assigned the task of managing the building system. Hence, product development is not a separate process within the companies, but rather an activity that is undertaken on project-by-project basis. Therefore, changes in the building system over time are not traceable and there is a risk for reinvention of solutions that have already been used and, more seriously the lack of a product development process prevents the use of coherent modularization strategies and consistent handling of rules associated with the building system.

4.3 Precast Concrete Elements

The studied Swedish concrete element company designs, manufactures and sells precast concrete structures for housing, offices, industries and farm buildings. Production capacity is 400 000 m² cast area per year at full utilization. In the factory, concrete elements, filigree floors and double walls are produced. In a building project, this production method means that walls and joists are produced at the plant, and then filled with concrete at the building site. No stock is kept at the factory; production and logistics are intended to deliver building components when needed, according to “just in time” principles. The components are placed on loading pallets in assembly order according to the erection plan. At delivery, the double walls are ready for installation, since electronic boxes, electronic tubes, sleeve couplings and recesses are fitted at the factory.

4.3.1 Process Model

An overall model of the process at the precast concrete company, in IDEF0 diagram form, is shown in Fig. 4. As illustrated in the diagram, a project starts when the marketing and sales department receives an order to deliver precast concrete structures for a building project. The sales department sends a number of documents, with analogical information on paper, to the design department, then product specifications of double wall elements and filigree floor elements are produced in AcadWand and AcadDecke (developed by IDAT), a CAD-system for the precast concrete industry. To increase flexibility the plant has also adapted its ICT system to enable design with IMPACT, a Swedish software package (developed by StruSoft) for the precast industry. This makes it possible to buy designs from consultants with access to these systems.

When elements have been specified, the system generates a machine file. To enable this, the CAD-system has been adapted according to the production control and monitoring system. The design department receives basic data digitally from architects and installation contractors as .dwg or .plt files.

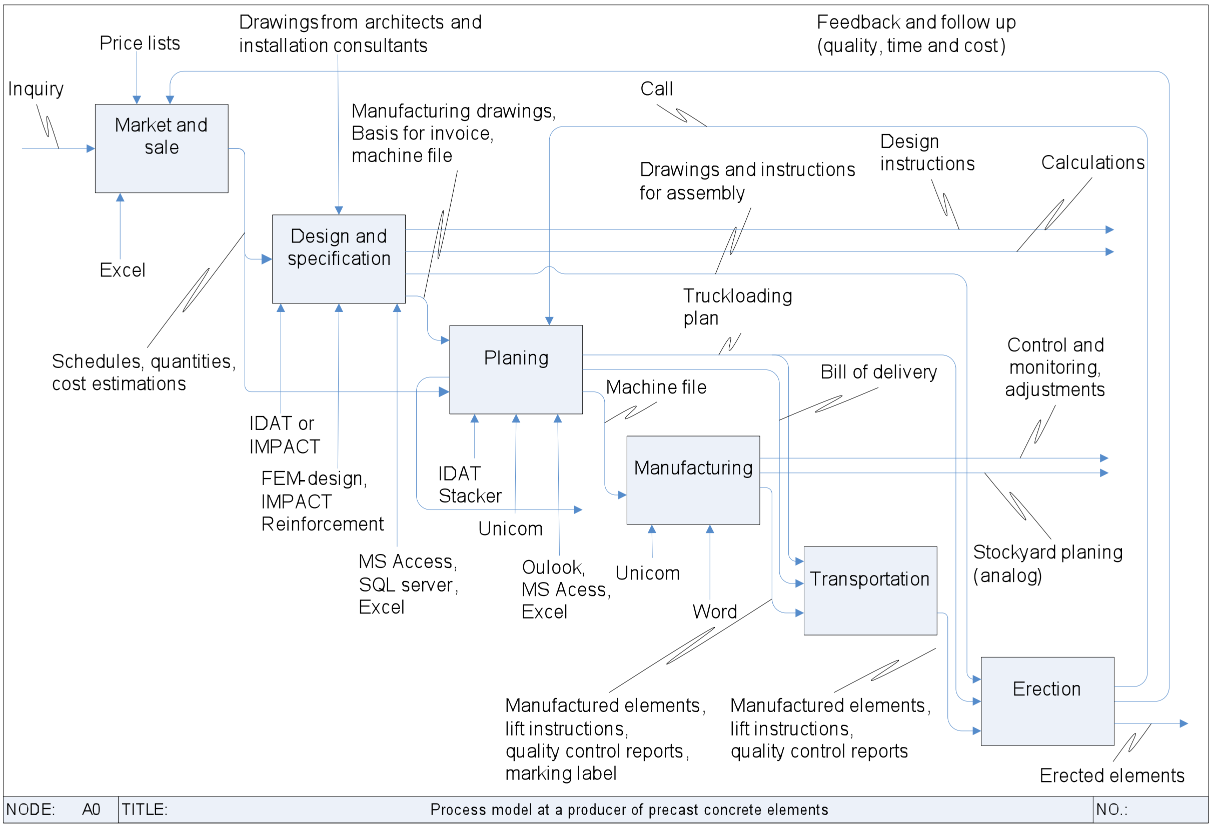

FIG 4: IDEF0 process and information model for the Swedish precast concrete company (element producer 2 in table 1)

During planning pre-production engineering is conducted, in which the generated machine file is tested by an error search before it is sent to the manufacturing apparatus via the control and monitoring system. In the planning tool IDAT Stacker a loading and detailed plan is made to determine the optimal range of production. The order of assembly on the pallets determines how the elements should be loaded, and thus the order in which the elements should be manufactured. The planning department also prints the construction drawings.

In IDAT Stacker the machine file is prepared for manufacturing. The file is sent to a control and monitoring system called Unicom. Here, any required adjustments to the machine equipment are made. Labels are printed from the system to keep track of the elements during transport. The manufacturing department provides the transport company with documents for inherent control. Lifting instructions are described in Word documents. The documentation of any temporary storage and loading plans is handled analogically at the plant. The planning department creates a delivery note for the transport company, and loading lists for both the transport company and the erection company.

During the interviews the personnel were clearly aware of the sub-processes and had mutual agreement regarding most aspects of the process relevant to their work, but such awareness was much less apparent when trying to map the information flow during the process. Furthermore, no defined product development process could be described, even though there is a close linkage between product development and the development of the production system due to the highly automated production line (so every change in the product affects the production system and vice versa).

4.3.2 ICT Model

Corresponding to the process and information model, there is an ICT system model showing interoperability between some (but not all) of the systems involved in the process, see Fig. 5. The ICT systems use different databases, and for them to be able to communicate with other systems several interfaces have been developed between different systems. The IDAT solution consists of a database and three main software modules (An administration, a “stacker” and a design tool module). The administration module handles the projects, and administrates the data files and the database. The “Stacker” module handles the data concerning the manufacturing process, and the “Design tool” module uses AutoCAD ADT to allow the user to design the required concrete elements, in a CAD environment. The product data used in the design and manufacturing process are stored in a MS SQL-database, and MS Access is used as a user interface to communicate with the database.

With the IMPACT solution, product data used in the design process are managed in an Ingres database and design work is carried out in a module integrated within the AutoCAD ADT system. The machine file is generated through IDAT or IMPACT. The control system, UniCAM, uses a MS Access database to manage the data during the manufacturing process.

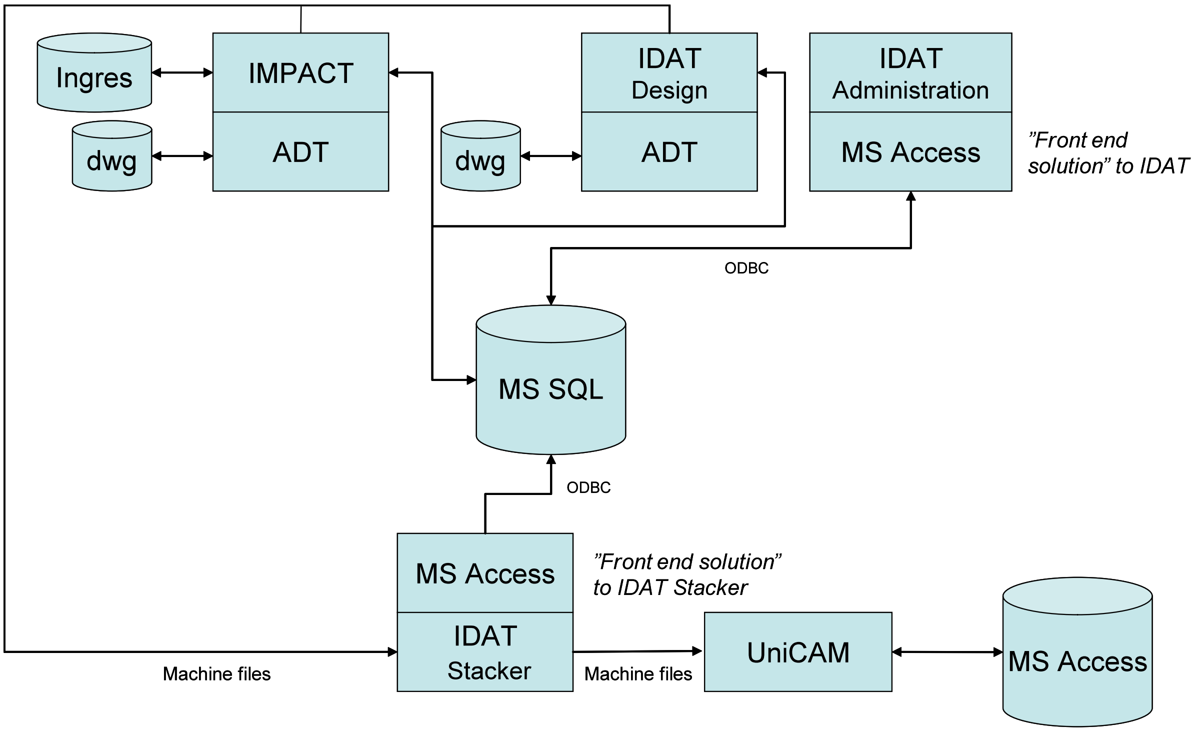

FIG 5: ICT model of the process at the Swedish precast concrete company (element producer 2 in table 1)

4.3.3 Product Range Documentation

In this case company there is no documentation of the product range to communicate with different stakeholders. However, the product range could be found in the information structure compiled in the databases and the CAD applications in IDAT or IMPACT. To illustrate the product range offered by the precast concrete company we use IMPACT as an example. For each precast company IMPACT develops a factory standard, which includes a product structure and allowed variants of the double walls. An extract showing the variants that could appear for each type of material used is presented in Fig. 6. The labels are numbers used for the identification of various articles managed at the company.

Relations and rules that define how different sub-assemblies and parts connect to each other are also implemented in IMPACT. In interviews with the employees at the company and the managing director of the company that developed IMPACT it was clearly apparent that the procedure applied to set these rules and relations in attempts to capture relevant domain knowledge is time-consuming when there is no formal independent documentation of the product range.

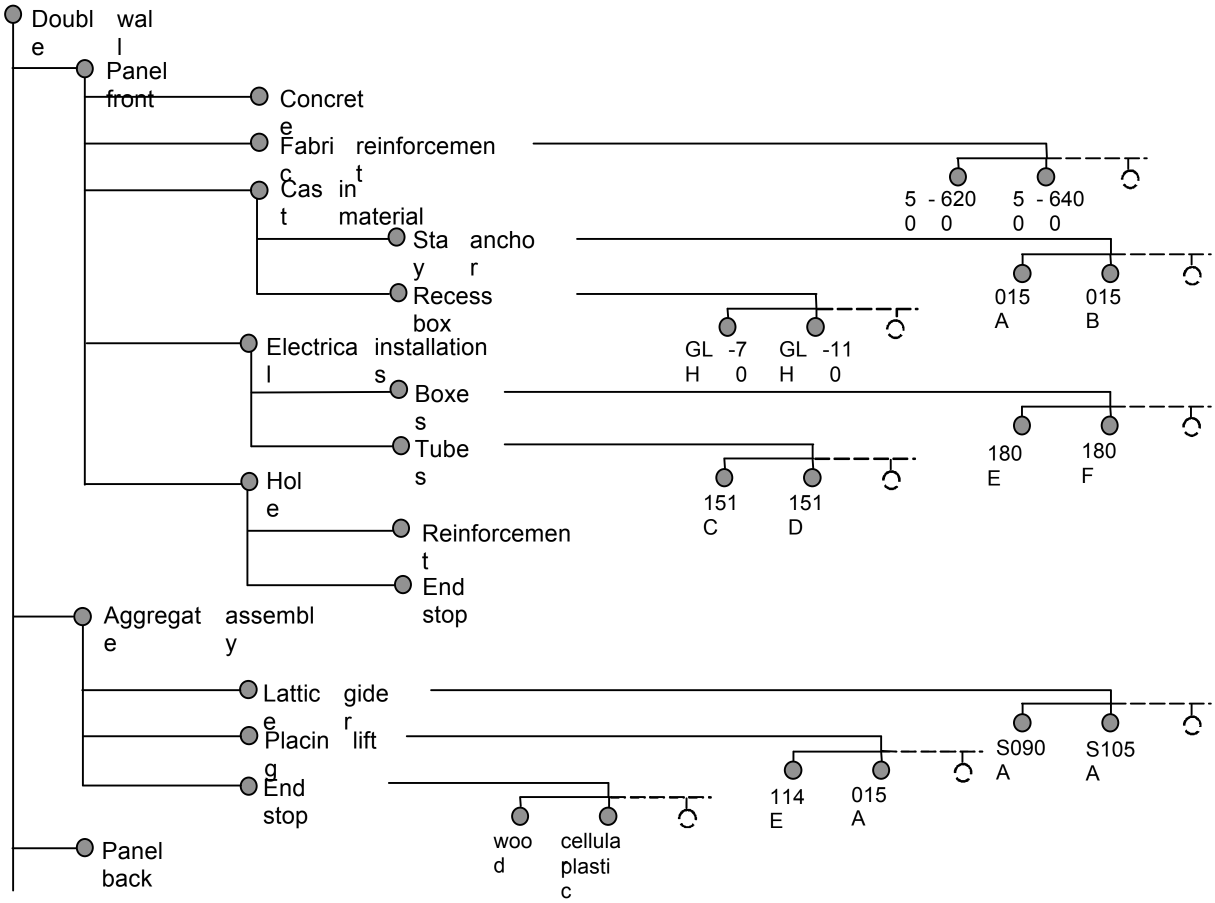

FIG 6: Extract from a product structure in IMPACT of variants in the design of a double wall that could be produced by the Swedish precast concrete company (element producer 2 in table 1)

5. INFORMATION MANAGEMENT ANALYSIS

Our analysis of the current situation in the case companies shows that much work remains to be done to implement rational and effective information management systems, especially within the studied timber frame companies. The systems are more closely integrated in the company that produces precast concrete elements, but even here potential improvements have been identified. Three main aspects of information management at the companies included in the study that could be substantially improved have been identified:

- Process orientation
- Product range documentation
- Information systems strategy

5.1 Process orientation

In this multiple case study the investigated companies in both the timber frame construction and precast concrete industries showed a lack of understanding of their existing business processes as well as difficulties in communicating them to other stakeholders. These deficiencies were clear even during the interviews with employees of the companies, since the interviewees were unable to describe their respective companies' workflows. None of the companies in the case study appear to have a distinct product development process in which building platforms are defined, instead major efforts are put into the design and adaption of every customer order, thereby exacerbating the lack of clarity of product definitions and the tendency of the designers to make changes in every project.

The industrial producers of the modular timber houses examined here need to gain more knowledge of the benefits they could acquire from a product development process. The findings indicate that there is an urgent need to introduce a product development process that accounts for the specific conditions of house manufacturing. At the manufacturer of precast concrete elements there is awareness that the product development affects the manufacturing process due to the high degree of automation. However, product development is not considered a separate process, and thus there is a lack of strategy concerning issues other than the feasibility of manufacturing new or modified products.

5.2 Product range documentation

In all of the studied companies there is a need to describe the product range thoroughly in a formal way that provides a better overview than the current approach. The incomplete descriptions of the offered products do not cover the full range that the companies can provide customers and leave much scope for interpretation in every project. A contributory reason for the under-definition of the product ranges are that opinions differ amongst staff in the companies regarding the product assortment and its definition, so product specifications cannot be too rigorous. The overall product descriptions of the product ranges at the precast concrete company are incorporated in program instructions of the design module tools. Nevertheless, there are no visual descriptions of the product range that could be used to communicate with various stakeholders or support a product development process. Hence, one objective that has to be considered in both the timber frame and precast concrete companies is to internally agree on a mutual company view of the product range.

Timber frame house manufacturing is often seen as a trade with great traditions and has always been dependent on skilled craftsmen. Customer demands are fulfilled by applying specific solutions, but the same customer request may be fulfilled by various solutions depending on the designer, which results in unwanted product variety. A contributory factor to this variety is the lack of guidance provided by the CAD tools at the six timber frame manufacturers included in this case study. In contrast, at the precast concrete manufacturer the CAD tools do provide guidance, and demands for product variety are met by adding more part types and interfaces, which rapidly increases the complexity of the products, and the associated information. More variety means more product articles to manage in an information system, and thus higher costs (Ulrich 1995). For the investigated precast concrete manufacturer, its automated production equipment restrains product variety. In early stages of the process the company has to either accept or decline an order depending on whether or not its design is compatible with its production equipment, which sets the parameters of its product variety, since the costs of adjusting it to suit single, customized orders would widely exceed any profit.

A requirement for using ICT tools optimally to manage house design and manufacture is a formal description of the complete product range (Lee et al 2007, Hvam and Riis 1999), which should be provided by either product modeling of existing products or a product development process. However, there are no such formal descriptions as yet at any of the companies included in the study. Hence there is a need to create them, especially for the timber frame house companies, which lack product models that describe their products. Instead, they regard the drawings that describe the various elements they manufacture as their product documentation, and information associated with specific applications or types of document types is stored in various forms (analog or digital) with little interoperability. Furthermore, the documentation is incomplete and could not be used as a basis for implementation in an ICT system (Hvam et al, 2008) due to the lack of a data model that facilitates information management involving multiple systems.

When constructing a complex product (a building for instance) from modules, the addition of more parts rapidly increases the complexity of the product and the possible interactions amongst the parts (Erixon, 1998), which thus increases the interfaces required and the amounts of associated information. Hence, managing the manufacture of a complex product requires well-defined product structures and well-developed information systems; the simpler the product model can be kept, the more efficiently it can be managed. For buildings this is especially relevant because of the complexity and high numbers of components they contain. However, regardless of the type of product being made, it is important to thoroughly define the product structures in order to maximize the efficiency of the information management.

5.3 Information systems strategy

In the precast concrete case company the information system includes several data models describing different aspects of the product and the manufacturing process. Consequently, there is a more refined strategy for managing information than in the timber frame construction companies. Nevertheless, synchronization between models and the production of information in the product development process could be improved. A hindrance is that the description of the product is embedded in different ICT systems and not accessible in a visual format to facilitate communication with different stakeholders. An alternative for the company is to develop an independent product model that supports the company process model and the product range, thereby improving the interoperability between the different data models.

Many complications arise when information has to be transferred from one system to another within all of the studied companies. This is a common complication associated with inadequate information management and information system strategies within the companies. For example, computer applications used within the timber frame companies are basically the same as those used in traditional building design, purchase and scheduling. However, these tools may not be optimal for companies that straddle construction and manufacture. Current applications for construction do not provide sufficient detail and ability to structure information in a way that facilitates industrialized construction. In addition to the companies' inability to specify appropriate demands for ICT tools, there is a pronounced lack of capability to formulate long-term information system strategies that align with the strategies for products and manufacturing systems.

6. CONCLUSIONS

Systematic information management and better tailored information systems could yield substantial benefits for the timber frame manufacturers and precast concrete element manufacturer included in this study. It is apparent that structuring information more effectively, and applying a holistic information strategy at management level that incorporates use of information systems throughout the company as a whole could considerably reduce the costs of information processing. In order to realize these improvements, companies will have to prioritize the following areas:

- Describing the relevant processes formally
- Explicitly describe the product range and its variety
- Creating an approporiate, interoperable information systems strategy

Based on the case study findings, the authors conclude that the general level of knowledge concerning information management in industrialized construction within Sweden must be increased. This will hopefully lead to better and more precise demands for information systems that can be subsequently supported by specific hardware and software. For a company that is eager to boost productivity through tailored use of ICT, more knowledge should first be acquired about what they want to accomplish through the use of ICT (rather than seeking tools for specific applications. Industrialization should change perspectives on not just the manufacturing system, but also on information management. Higher levels of industrialization place greater, more sophisticated demands on information management, thus investments in industrial production also require adequate information management.

The need for a product data model that accounts for the specific needs of industrial house manufacturers has been recognized in this article. Future priorities in this respect include development of a model capable of describing the product range of industrial construction companies that could facilitate information management in terms of product specification and production. Such a model should consider the three critical areas specified in this article.

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III

PRODUCT MODELING OF CONFIGURABLE BUILDING SYSTEMS – A CASE STUDY

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SUMMARY:
This paper investigates a Swedish house manufactures building system regarding the documentation and information structures. The aim is to evaluate how product modeling technology can be used to facilitate product customization. By dividing the product in 4 different views the complexity of the product can be reduced and each view represents the interest of customer, engineering, production and assembly respectively. The analysis shows that the connections between the different views, i.e. the information transfer, is an area for potential improvements and little attention has been devoted to transfer information upstream from manufacturing and engineering to the customer view. The lack of information transfer can often lead to ad-hoc solutions in the customization process. We believe that successful cooperation and information exchange between these four views is the key to future development and customize-to-order configuration.

KEYWORDS: *industrialized construction, modular houses, information management, building product model, product customization,*

1. INTRODUCTION

Production methods of Swedish house manufacturers vary from almost manual carpentry to highly automated manufacturing units. Earlier studies in Sweden have concluded that information management in Swedish timber house manufacturing is relatively poor and similar to on-site construction, Johnsson et al (2006), Persson et al (2009). The information gaps between sales, engineering and production departments often lead to situations where customer requirements are implemented using ad-hoc solutions that are not suitable for the existing production system. Traditional methods and use of project oriented IT-tools do not support the industrialization and automation of the house manufacturing industry, Johnsson et al (2007). Therefore, new methods and IT systems need to be developed integrated in the design and production of manufactured houses.

Many of the developed building systems have evolved during decades and cannot easily be adapted to fluctuating markets. Also, the lack of proper description of the building system makes the system harder to adapt to volatile customers' requirements. The product documentation often consists of drawing files in CAD libraries (predominantly AutoCAD) that make the products difficult to use in a customization process. According to Nasereddin et al (2007), adequate documentation of the product structure and customization processes is essential for the productivity and quality of the end product. The "ad-hoc" customization of initially well-standardized technical solutions is one of the main reasons for the decreasing profits in the Swedish prefabricated single-house industry, Brege (2008).

Development of modularized product platforms is one strategy for mass customization, Erixon (1998). The customization process needs information of the product structure, its constraints as well as the customer requirements in order to develop a successful configuration and modularization strategy, Yang et al (2008).

2. OBJECTIVES AND METHOD

The objective of the study is to investigate how product modeling technology can be used by industrialized house manufacturers in the customization of a building system. More specifically three research questions are formulated:

1. How can an existing building system be documented using product modeling methodology to cover the process from sales to the realization of a customized building?
2. How well can the existing building system be adapted to customers' requirements?
3. How is the flow of information from sales to realization of the building affected by the use of product modeling technology?

An investigation of a Swedish company has been performed where three methods of collecting information were used for the case study of the building system in the research project:

- Studying drawings and documents of the building system as well as the production system
- Interviews with sales and engineering department
- Workshops with engineering department to verify the product model of the building system

The existing description of the building system is used as a basis for creating the product structure presented in section 4. From drawings and documents a first description of the product design and production constraints was established. This part of the study was performed with the intention to create a first product model of the case study building system. The information was then illustrated in product views, see section 4.4.1-4.4.4, which were used to refine and verify the product structure of the building system with the engineering department in a workshop. The refined version presented after the workshop is the version published in this paper.

Two methods were used to define a set of popular requirements from a typical customer used in the study described in section 4.5:

- Information gathered from a Swedish survey of housing standards, Horsman W. M. (2008)
- Interviews with the sales department in the company

3. THEORY

3.1 Information and product models

An information model represents a part of the real world, in some cases referred to as the universe of discourse, Björk (1995). All information models are unique, as well as the process of creating it, Schenck and Wilson (1994). According to Schenck and Wilson (1994), an information model should be precise, complete, non-ambiguous, minimally redundant and implementation independent.

Companies that develop, manufacture and sell complex products need to define and manage product information during all stages of the life cycle, Claesson et al (2001). These information models that contain data of both the product and the processes supporting the product's life cycle are generally referred to as product models. A building information model, BIM, is a product model defined for building products. A well known model standard for buildings is BuildingSmart, Industry Foundation Classes (IFC), BuildingSmart (2009). The team defining the set of rules used to interpret the data in the product model, i.e. the model schema, consists of product modeling experts and domain experts possessing knowledge of the product and the supporting life cycle processes. The definition of product model schemas often contains a mix of various methodologies, for example top-down and bottom-up in an iterative process, Hvam et al (2008), Schenck and Wilson (1994). There are several methods, which could be applicable for definition of product models in construction, Hvam et al (2008), Lee et al (2007).

According to Björk (1995), the creation of a product model for buildings starts by defining the classes of the main building parts and the systems they form, i.e. structural system, installation system etc. The next step is the definition of the most important attributes of these classes and the relationships between these object classes needed in many applications. A similar approach is suggested by Schenck and Wilson (1994), where basic classes and relationships often can be extracted from the domain experts by frequently used nouns and verbs, were nouns represent the physical objects and verbs represent the relationships between the objects.

There are aspects that have significance in the choice of information modeling language, Björk (1995):

- Capability for modeling the semantics of the universe of discourse without simplifications caused by the information modeling language
- Capability for modeling the designer's intents and aims
- Support for the evolutionary process of design (extendibility of the schema)
- Usefulness for the exchange of data between heterogeneous computer applications in construction
- Technical feasibility for implementation using current commercial software
- Realistic possibilities for achieving standardization (in terms of reaching consensus in standardization bodies and expenditure)

A popular language used in many product model applications such as the STEP and IFC model standard is the EXPRESS modeling language, Schenck and Wilson (1994).

3.2 Product configuration

Product configuration is described by Hvam et al (2008) as an effective mean of structuring products and standardization, but also a way of presenting the product for the customer. Also, the structuring of products in product models becomes a common view of the product ranges in the company that can be shared by the people involved in the support of the product life cycle, e.g. sales, design, production and maintenance. Before a configuration project is initiated, the following issues need to resolved, Hvam et al (2008):

- The range of products to be part of a configuration system need to be structured in some form of product structure. Often conflicting views exist in the company regarding rules, degree of detail etc., these issues have to be resolved before any product modeling initiative is launched.
- Companies also have to decide what parts of the product range that should be included in a product configuration system. Probably, not all products are suitable for configuration.
- The information needed for the product configuration project need to be collected. This information often resides in documents, CAD files and different type of management systems such as ERP, SCM and CRM as well as in the knowledge of product specialists in the company.
- How should product information be stored, updated and maintained? The product model will have to be constructed so that these parameters are effectively considered.

Leckner & Lacher (2003) pointed out that customer oriented product modeling is governed by the flexibility required in the product configuration process. They defined different types of flexibility or the degrees of freedom of a product:

- *Alternative component model* were the customer can choose exactly one from a set of exclusive alternative components;
- *Optional component model* where the customer can select optional components not obligatory for the product in an add-on configuration process;
- *Attribute enumerated set model* where the customer can choose a component with one value from a predefined set of possible values;
- *Attribute numerical interval model* where the customer can choose a component with one value within an interval boundary.

The result of a product configuration is a customer specific product model where the product properties and functions are determined and specifications of what modules and components will be produced and assembled are given, Jørgensen (2001).

3.3 Customer requirements

The increasing demands on products matching customers' individual preferences and tastes put pressure on manufacturing companies to offer more product varieties, Veenstra et al (2006). Still, the economical benefits of mass production need to be retained to keep the production cost at an acceptable level, Hofman et al (2006).

Since the cost of developing a building system is high, system analysis and customer surveys of the target market segments are important in the design of modularized product platforms, Bertelsen (2005). This approach is well known in the manufacturing industry but often foreseen in construction companies since customer requirements are treated only in the specific project and often specified by the client in a building program. A product platform needs to be adapted to a variety of customers in the targeted market segment to be competitive. A number of methods have been developed to map customer demands against product properties. Quality Function Deployment (QFD) is a widely used method that emerged in Japan, Akao (1990). QFD introduces the customer needs and requirements early and in many ways govern the product development process.

The transformation of customers' values and requirements into product properties are often performed by a multi-disciplinary QFD-team. In traditional procurement systems, when design and construction is done by different participants, the QFD methodology can create problems. The "cross-functionality" approach often used when conducting a QFD, can be hard to achieve in traditional construction projects where the design, engineering and production planning and execution phases are separated. The QFD methodology can be suited for projects were one part is responsible for both the design and production and the functional requirements for both the product and the production can be defined in an early stage of the project, and not as a parade of trades, Dikmen et al (2004).

The QFD analysis needs the customer values or requirements as input. This is often evaluated in market surveys where different market segments are investigated using statistics and customer questionnaires, Eldin et al (2003).

4. CASE STUDY

4.1 Company

The investigated company is one of Sweden's leading modular family house manufacturers. Since the start over 50 years ago, approximately 43 000 houses have been built. The company delivers turnkey houses and takes total responsibility for the delivery. Sales, design, manufacturing and on-site assembly are performed by in-house staff. The company exports houses to Denmark, Germany and Japan. Customers include both private individuals and business to business clients. In 2008, the turnover was € 91 Million and in total the company employs a workforce of approximately 320 people. Houses are manufactured in both contemporary and classic designs and the targeted end customer group is predominantly middle- and upper middle class.

4.2 The product family investigated

The investigated product family is an affordable house model offered by the manufacturer, it contains five models all based on the same construction principles. The design is classic/contemporary with a relatively high standard regarding kitchen appliances, surface materials etc. All models are detached houses spanning between 100-180 square meters of living space, manufactured in the production facilities of the manufacturer and delivered and assembled as turn-key house to the customer.

The product family is offered at a competitive price with limited possibilities for customization. The product family is designed by the company associated architect with the intention of creating solutions that do not need to be modified. The strategy is to streamline house production and minimize one-of-a-kind operations. The customization options are mainly selection of façade, kitchen appliances and wall coverings.

4.3 Product documentation system

CAD is the predominant product description system for the investigated product family. AutoCAD is used for design and customization of all house models in the company. The AutoCAD system is used for the architectural, structural and HVAC design. Production design rules have been implemented in AutoCAD using VBA interface (Visual Basic Application). The production design rules with associated parameters are stored in an MS Access database. The company is also using an in-house developed MRP/CRM-system (Material Resource Planning/Customer Relation Management) that keeps track of stock and orders along with customer data. Product related information is consequently kept in two systems, the AutoCAD and MRP system, dependent where the information is created, i.e. design information is kept in the CAD system and information related to purchase, stock and customer is kept in the MRP/CRM system.

As a complement to the information in the CAD system, written manuals exist that contain information about rules and limitations of the building system. There is also a manual describing the design rules of the building system to an external audience of architects, structural engineers and sales agents. It covers the main aspects such as, facade heights, floor plan, openings, roof and floor structure, etc. Other product related information is mostly distributed within the organization through documents and drawings.

4.3 Current process

The sales department is often asked to adapt the offered product to fit customer's individual needs. These changes are often not possible to fulfill without violating the rules of the building system. Although the managements' intention on a relatively restricted customization policy, changes of the original concept is often introduced by the sales department to satisfy the customer. Consequently, these adaptations cause problems both in engineering and production when ad-hoc solutions need to be applied to specific customers. Also, the implications, i.e. additional costs for adaption of the product by the engineering and production units, are hard to evaluate. Furthermore, these ad-hoc solutions are often not reused in other projects since the specific solutions are not analyzed in an attempt to modify and incorporate the changes in the product concept.

These findings from interviews with the sales and engineering emphasizes that there are important issues that need to be resolved:

- The product documentation needs to be adapted to the different processes in the company, e.g. in sales, engineering and production views.
- Changes in one view, e.g. sales view, should be easily traceable in the engineering and production views and vice versa.
- Changes of the product concept affecting the production system should be made in a product development process from a strategic point of view making the building product more adaptable to customers' requirements. Otherwise, the costs of introducing ad-hoc solutions should be part of the product offer to the customer.

Next, we will present a conceptual solution of the product documentation issue using different views of a product model of the investigated product family.

4.4 Organizing the product information in product views

Hvam et al (2008) uses a methodology based on the representation of the product in a hierarchical structure based on Unified Model Language (UML). These representations or *product views* of the product model are used to package and present the product information for a targeted set of stakeholders, (knowledge domain). IKEA is an example of a company working with different product views. IKEA's kitchen configuration program makes it possible to design and get a price of a custom made kitchen directly on their website, IKEA (2009). Information essential for the customer such as cabin doors and colors etc, are presented in the customer view of the product. Then, in the production view of the customized kitchen the types of colors and cabin doors is described with article numbers, color codes and other related information used in the production of the custom made kitchen. This information is added in the manufacturers CAD programs different from the one used on the website. The use of process adapted product views of the same product is common in the manufacturing industry and to some extent also in the AEC (Architectural, Engineering and Construction) industry. However, the different views in the AEC industry is mostly connected to the architectural, HVAC and structural disciplines using drawings and documents making the integration and coordination between different disciplines a tedious manual task prone to errors, Jongeling and Olofsson (2007).

The product views with their related product structures also constitute the point of departure for organizing, storing and communicating product information both internally and externally, which would facilitate the information sharing in the customization process, Hvam et al (2008), Johnson et al (2007).

The following product views were defined in the case study:

- The *Customer view* represents an instance of the product model as it seen by end customers and sales agents which represent the company. This view represents the features of the product family requested by customers.

- The *Engineering view* represents the various customized alternatives of the product model from an engineering point of view. Here the different systems such as structural, installation, etc. are shown important for the technical realization of the product features requested by the customers.

- The *Production view* describes the different building parts to be manufactured at the production facility. It contains information relevant for the supply chain and the factory production units.

- The *Assembly view* describes how the product will be assembled on site. Assembly instructions, the order of delivery and assembly of prefabricated elements, schedules etc are example of information relevant in the assembly view.

Compared to Hvam et al (2008), the assembly view has been added to the product views in the case study.

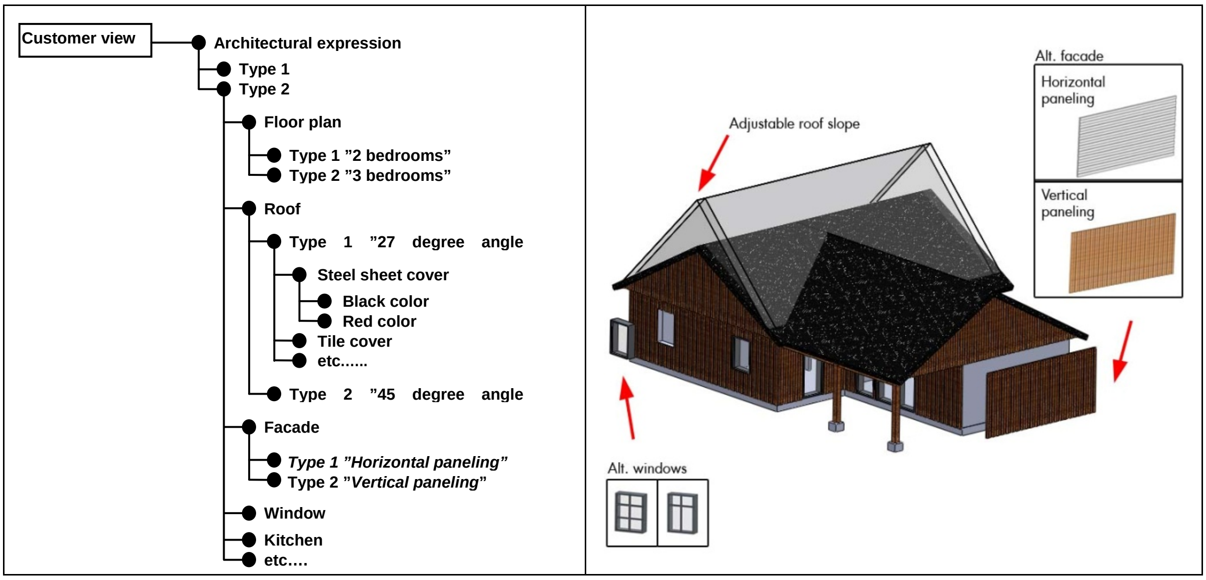
4.4.1 Customers view

Fig. 1 a) – d) show the customers view of the product family. The customization options consist of selecting between two types (henceforth referred to as type 1 and 2) of models within the product family. Within e.g. the type 1 concept the customer can for example choose from altering the floor plan to consist of either two or three bedrooms, an adjustable roof slope with two optional colors (red, black), two types of façade paneling and two types of windows. Table 1 summarizes the flexibility types of the customer views of the product family concept according to Leckner & Lacher (2003).

Table 1: Flexibility of the product family in the customer view

Alternative	**Flexibility**
Type 1 or Type 2	Alternative component model
Type 2 – Floor plans: 2 or 3 bedrooms	Optional component model
Type 2 – Roof: 27^{o} or 45^{o}	Attribute enumerated set model
Type 2 – Roof: red or black color	Attribute enumerated set model
Type 2 – Façade: vertical or horizontal paneling	Attribute enumerated set model
Type 2– Façade: Window type 1 or 2	Attribute enumerated set model

The alternative floor plan with three bedrooms is not a true add-on configuration (optional component model) since the alternative will affect the size of the living room.



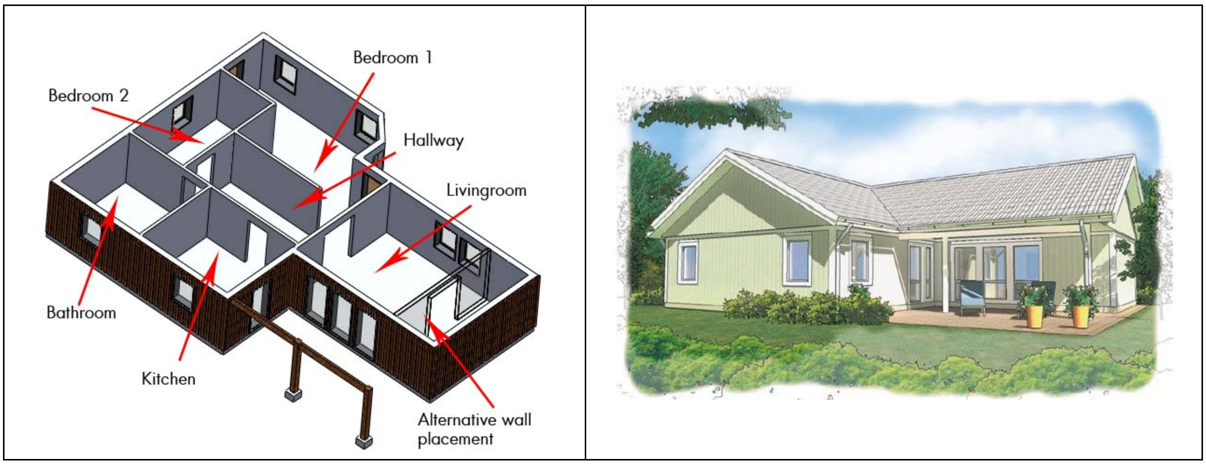


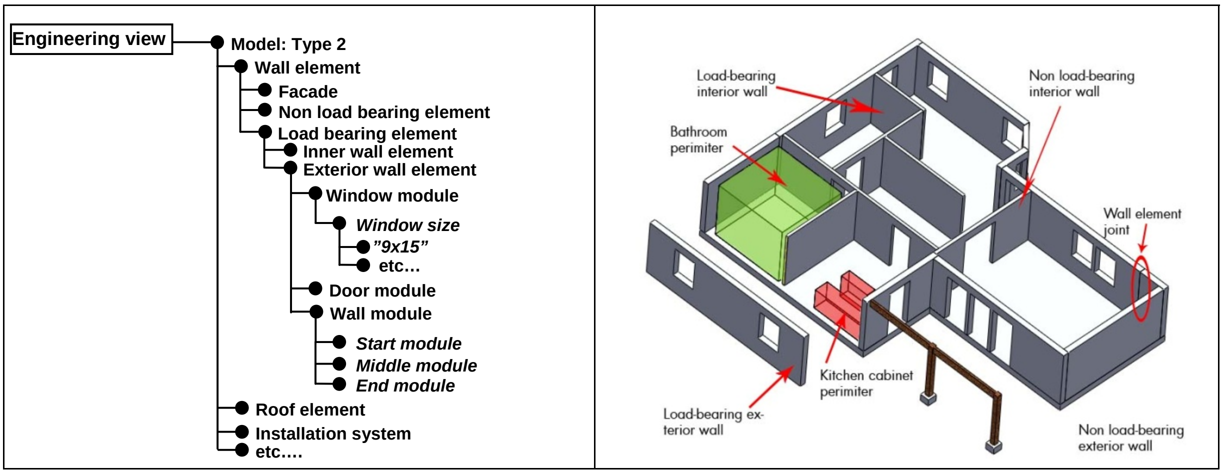
Figure 1: The customers view of the product family Type 2 alternative. Figure 1a) shows the product structure, 1b) the façade, 1c) the interior floor plan and 1d) an example how the configured product is presented for the customer.

The customer product view shows the choices that are important in the context of the sales process. Here the prominent parameters are; architectural expression of the floor plan, and exterior. The details of the structural system, installations etc. are not included since they are not important for the customer. Nevertheless, the engineering and production parameters need to be verified already in the sales stage to avoid the creation of ad-hoc solutions propagating downstream to the engineering and production stages.

4.4.2 Engineering view

Fig. 2 shows the engineering view ensuring that the customers' choices can be technically realized by the company. This view represents the technical solutions that fulfill the features requested by the customer. The engineering view is meant to be used in the design of new products or new features in a product family considering the constraints given by standards, regulations, production system, etc.

In the engineering view, the structural system of the product family is shown in Fig. 2a). The load bearing and non-load bearing wall blocks including openings for doors and windows are shown to be able to test the structural integrity of the product family model. In Fig. 2b) a space object has been inserted in the bathroom as a carrier of functional and customization requirements to the engineering view, e.g. bathroom requirements on the walls facing the bathroom. Fig. 2c) and 2d) shows how a wall can be decomposed or modularized in units that can be reused in product development. The combination of these engineering modules into the different wall types in the product must abide the rules of the production system, e.g. they must be able to be produced by the production system.



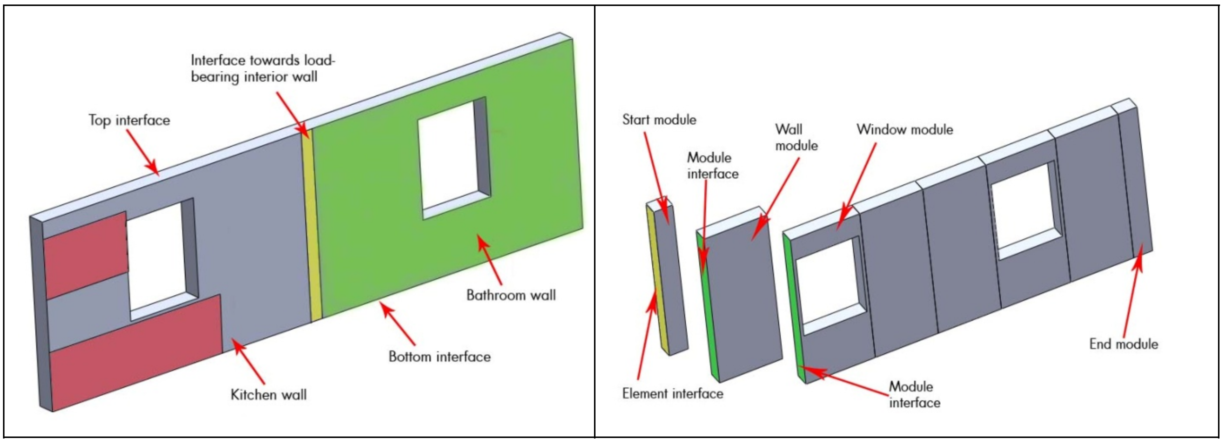
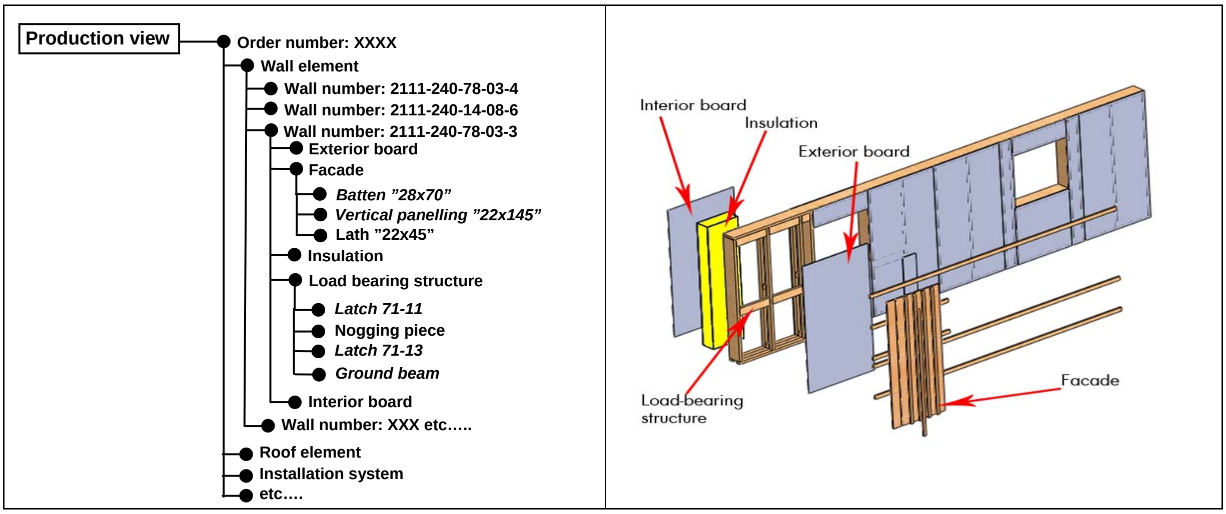


Figure 2: The Engineering view of the product family type 2. Figure 2a) shows the product structure, 2b) the structural view of the interior floor, 2c) an example of a load bearing exterior wall and 2d) its modular composition.

4.4.3 Production view

The production view gives a detailed description of the building parts to facilitate the pre-manufacturing in the factory. It contains information relevant for the supply chain and the production system. The production product structure can also be used to create the bill of materials, BOM, and hence link the production view to MRP (Material Resource Planning) and ERP (Enterprise Resource Planning) systems in the company.

Fig. 3 illustrates the product from the production point of view. Here, the elements to be pre-manufactured are presented with the necessary information for production. Fig. 3b) shows an exploded view of the wall, Fig. 3c) the wall framework while Fig. 3d) contains BOM list and information necessary for manufacturing of the wall assembly. CAD applications tools used in manufacturing industries are often possible to connect to various PDM (Product Data Management) and PLM (Product Lifecycle Management) systems. CAD applications used in the AEC industry often lack this possibility.



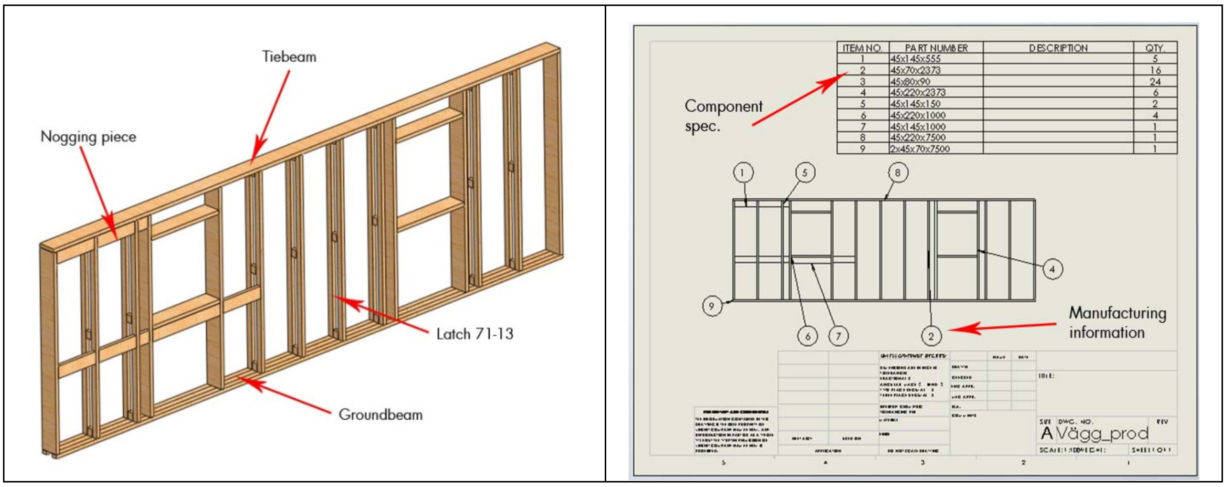
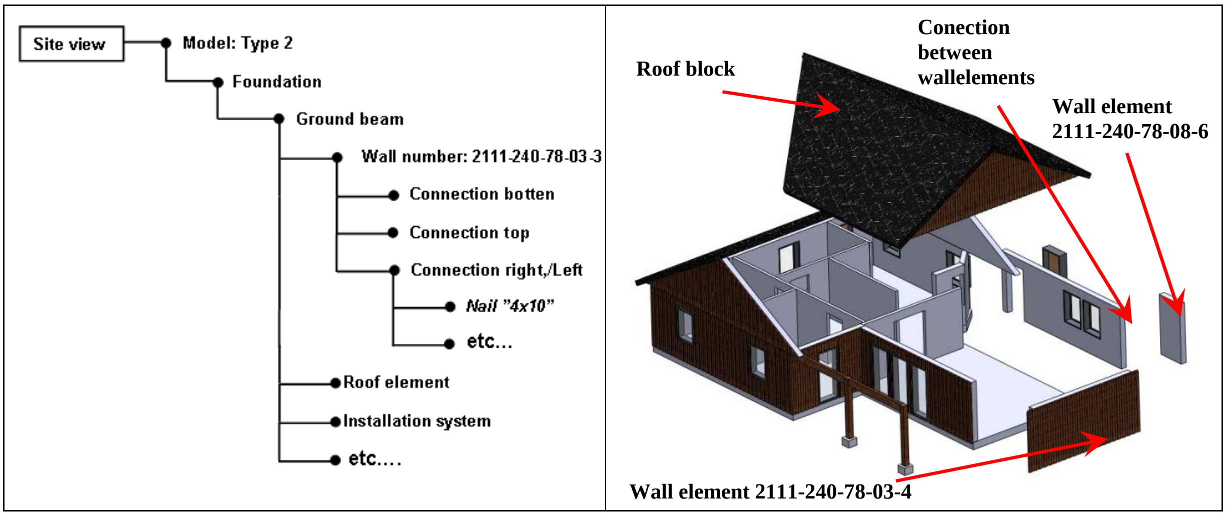


Figure 3: The Production view of a customized order. Figure 3a) shows the product structure, 3b) an exploded view of the highlighted wall element, 3c) the framework of the wall and 3d) its BOM list and manufacturing information.

4.4.4 Site view

Fig. 4 shows the site or assembly view that provides information on how the product will be assembled on site. Information needed in this view is assembly instructions, the order prefabricated elements such as roof blocks and wall elements need to be delivered to the assembly site and schedule. Fig. 4a) shows the assembly product structure, 4b) an exploded view of the product to be assembled, 4c) connection details between assembly components and 4d) a flow line view of the assembly schedule. The assembly drawing focuses on the connection between different elements to be assembled. The proposed scheduling method is flow-line or Line-of-Balance because of its ability to plan and analyze the assembly for work-flow and possibility to combine with 4D visualization, Jongeling and Olofsson (2007).



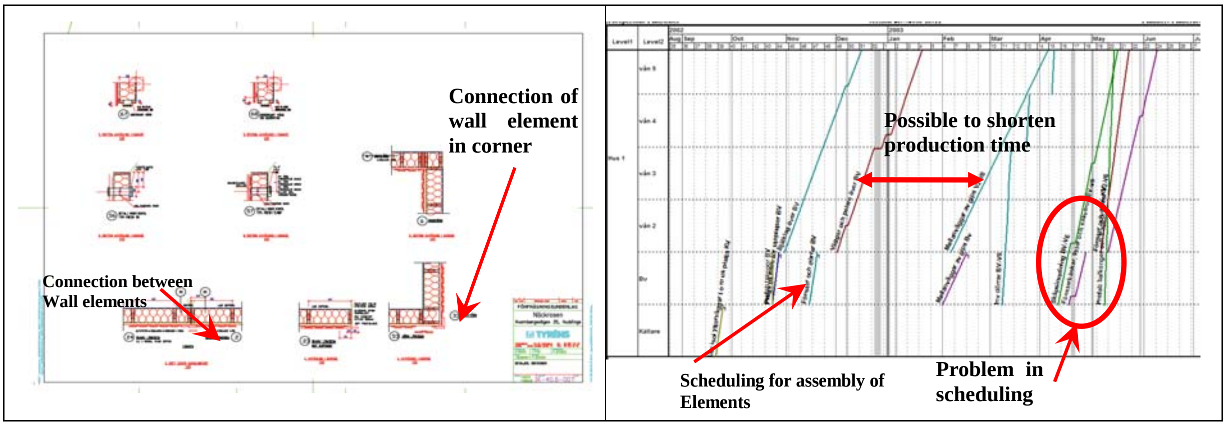


Figure 4: The Site view of a customized order. Figure 4a) shows the assembly product structure, 4b) an exploded view of the assembly structure, 3c) assembly drawing of connections and 4d) the assembly schedule expressed in a flow-line diagram.

Next, we will analyze the product family model, type 2 concept from a customers point of view represented by a recent Swedish customer survey performed on the Swedish housing market.

4.5 Customer Requirements

According to the company the house model are targeted towards families looking for a customized house with relative high standard regarding materials and construction but not with too many other choices, see possible alternatives in Table 1. Actually, the studied case company referred themselves as an engineering company focused more on the demands from the production department than demands from customers. However, if these models are to be successful on the market the offered alternatives must be based on market analysis of the consumer segment.

According to Eldin et al (2003), customers' requirements must be based on market research using surveys and interviews with prospective customers. To exemplify the importance of adapting the product to market trends, the product offers of the product model have been compared with a recent survey of the Swedish housing market regarding demands and wishes, Horsman W. M. (2008). The Internet survey, performed in 2008, received some 5000 answers where some 1600 answer came from people living around the city of Stockholm. The respondents varied in age between 18 to 65 years. The result of the survey was also confirmed with customer demands received by the sales office in Stockholm in interviews with key employees. In Table 2 the top ten demands from the survey and the willingness to pay are compared with the product offers of the product model.

Table 2 Customer top ten demands, Horsman W. M. (2008), compared with the product offers of the product model

Housing	Rank	Willingness to pay	Offer
The housing have central controlled functions that is connected to internet, such as possibility to check the fire stove, turn on alarm, etc.	1	34%	no
It is possible from a central place to control environmental climate systems and light system etc.	2	40%	no
There is a possibility to have built in speakers and media players etc.	3	25%	no
It is easy to rebuild the floor plan for handicap requirements	4	28%	no
The house is easy to access with Wheel chairs and baby carriage	5	28%	yes
Possibility to compensate for climate	6	38%	no
Flexible floor plan with for example movable walls etc.	6	18%	no
The housing is built in a way that lower sound disturbances between bedrooms etc.	8	40%	no
There is a high standard regarding kitchen and bathroom	9	55%	yes

The building is close to culture and activities performed in spare time for example restaurants and theaters etc.	10	28%	n. A

Remote control of indoor climate, flexible floor plans, noise reducing walls between rooms, high standard in kitchen, etc, are among the top alternatives which customers have a relatively high willingness to pay for. In a survey performed in Holland “type of kitchen” also ends up as the most important customization alternatives, Hofman et al (2006). These types of investigation provide valuable information on customization options for the house building manufacturers.

5. ANALYSIS

5.1 Organizing the product documentation

Product modeling initiatives have often tried to grasp complex product architectures of entire houses with structures in the same model. This has most certainly not been successful. Less complex information models of the reality (universe of discourse) and better adapted to working processes has probably a better chance of success, Sandberg et al (2008). As illustrated in section 4, the product model was structured in four views, capturing the information needs in the customization, engineering, production and assembly process at the site. The control over the product comes from the ability and the way these views are described and connected, i.e. the transformation of information downstream and upstream the value chain. Fig. 5 illustrates the connection between the different views.

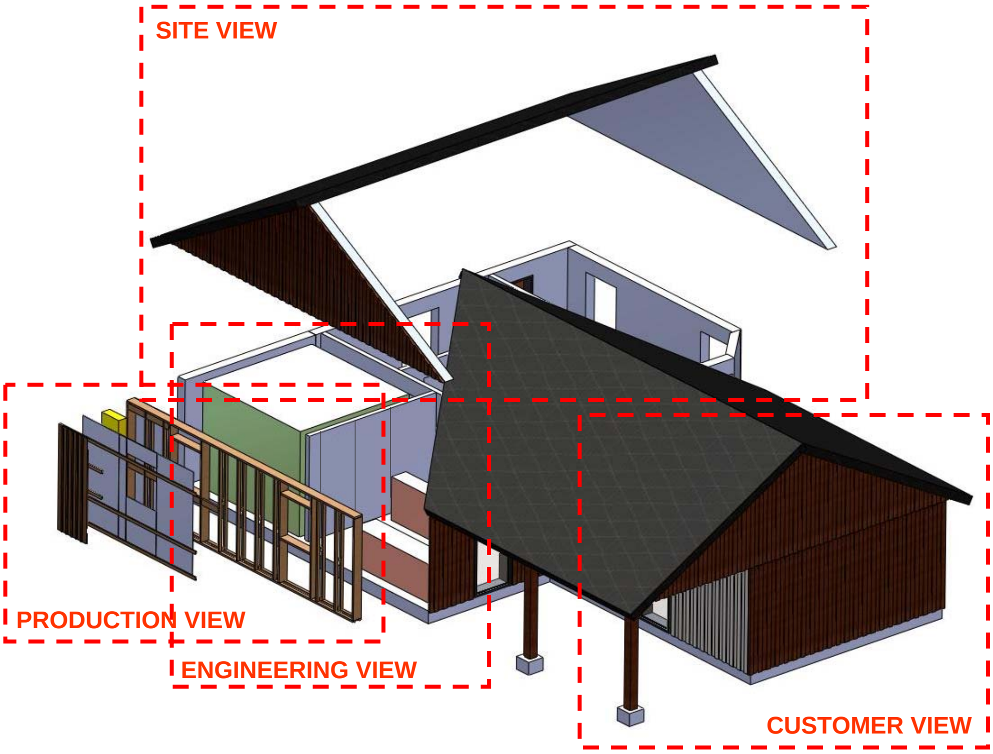


Figure 5: Describes the separate views in the same product and how they are connected and overlay each other

Today, most experiences from earlier projects are seldom documented; they exist only as tacit knowledge in people working at different departments, Sandberg et al (2008). The company knowledge of the product becomes fragmented since it can only be transferred to co-workers in close proximity. This was also evident in the case study company, since informal knowledge had been noted on personal copies of CAD files and product documents. Benefits of integration of product knowledge using product model technology are manifold; less problems with ad-hoc solutions, better and faster product specification process, ability to develop and modularize technical solutions to better match customer requirements, integration of the flow of information between sales, engineering, production and site assembly, etc. Today, there exists a multitude of product modeling technologies, and system that can manage complex products. However, most methods and tools are still limited to support the design, development and production of single products, Claesson et al (2001). The extent of the product family should be modeled (digitally represented), and IT-systems must be adapted to the manufacturer's product portfolio and economical and organizational abilities. Often only the geometric description of products generated by CAD systems is managed directly, Sudarsan et al (2005).

5.2 Customer requirements versus product offers

Many of the highest ranked customer needs cannot be offered by the product family investigated. The comparison between customer survey and the customization options indicates that there is a mismatch between product offers and requirements in the market segment. This can be one reason for the ad-hoc solutions observed in order to satisfy the customer. Another possible cause is the inability of the company to transfer information of rules and constraints of the building system to the sales organization. Also the company self image as an engineering company might underestimate the importance of adapting the building system to the end customer requirements. The product should be continuously developed to adapt to customers volatile requirements and trends in the market segment. Therefore, experiences from the sales department should always be analyzed and incorporated in development of the building system. New product options should only be implemented as a result of a strategic decision to develop the building system.

5.3 Information flow with product modeling technology

All orders are verified against a checklist, which describes the customization rules (constraints). It contains detailed information of the house to ensure that products can be efficiently manufactured. Although the checklist gives the impression that the company uses a bottom up approach, i.e. let the customer decide then adapt the design to the system. However, the interviews gives the opposite impression that a top-down approach is used – the customer chooses a model which then can be modified according to certain rules. According to sales office, they do not have contact with engineering and production departments before the customer signs the contract. However, to sell the product they need to agree on certain changes of the product, to be able to satisfy the customer. These statements indicates that the link between customer view and the other views (engineering, production and site) are weak. When the customization process violates the rules of the building system, this information is not automatically transferred to the engineering and production view which is a major source of ad-hoc solution in production. Attempts to reduce ad-hoc customization have been to offer fewer options, but this also increases the risk of removing the wrong options from a customer perspective.

It has also been shown that it is much easier for companies to transfer information downstream the value chain than transferring information, rules and constraints upstream, see Fig. 6. Thus, problems related to information transfer should be addressed by creating paths and tools for information exchange upstream the value chain and agree on mutual views of the product. If the information and constraints illustrated in the separate views can be described for all disciplines involved in the process "ad-hoc" solutions can be minimized. The constraints are often too many to manage without the support of integrated information systems such as PDM and ERP systems in the customization of the product.

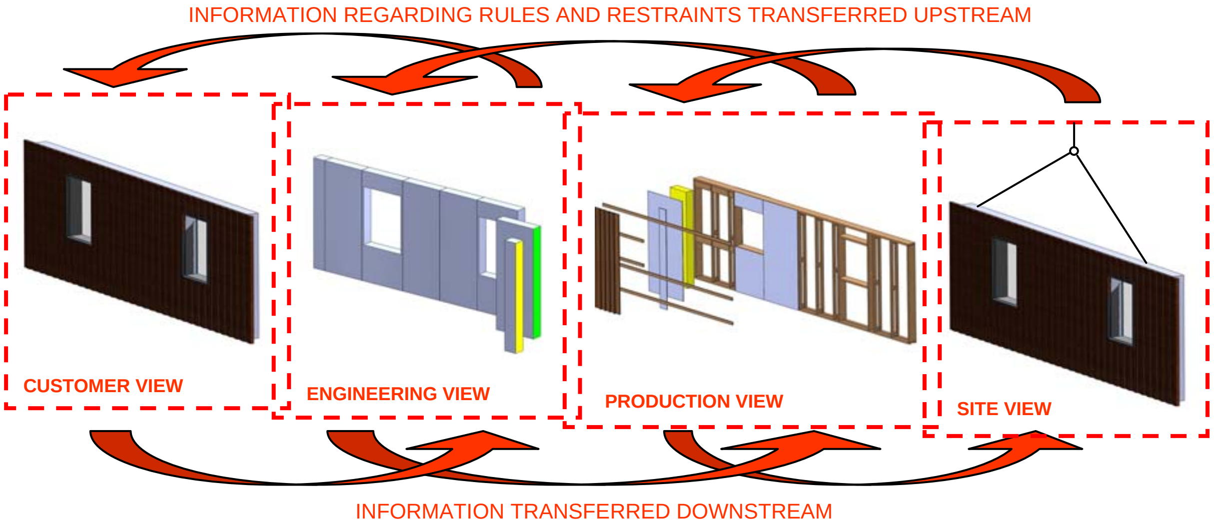


Figure 6: The connection and integration of information between the separate views

6. CONCLUSIONS

Product modeling is a suitable technology to describe the product structure of modular houses. It gives the manufacturers the opportunity to get a view of the entire product range. Creating adapted views makes the product structure less complex to implement. The integration between the different views consists of information transferred downstream from the customers view to the engineering, production and assembly view. The rules and constraints of the building system are transferred upstream from the assembly, production and engineering view to the customers view and hence define the customization limits of the product family. The case study also showed that product development of modular houses must start from customers' requirements. Too little attention of adapting the production system to the volatile customers' expectations increases the risk for ad-hoc solution propagating to manufacturing and assembly on-site with considerable higher cost as a result. Eventually the product will be harder sell. It is also evident that the ICT-tools used to create and manage the different views are view specific, as long as the information and constraints can be transferred between the tools. We believe that successful cooperation and information exchange between these four views is the key to future development and customize-to-order configuration.

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