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 predefined 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.

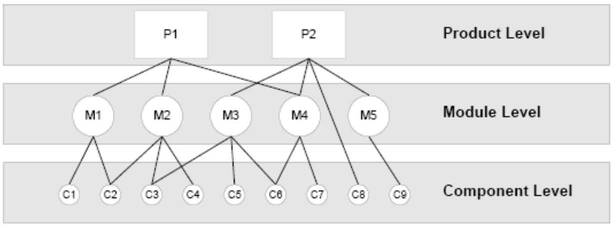

Figure 2. Combining components to modules and products, (Jørgensen 2005).

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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