ITcon

www.itcon.org - Journal of Information Technology in Construction - ISSN 1874-4753

INFORMATION MANAGEMENT IN INDUSTRIAL HOUSING DESIGN AND MANUFACTURE

PUBLISHED: June 2009 at http://www.itcon.org/2009/11
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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*

REFERENCE: *Persson S, Malmgren L, Johnsson H (2009) Information management in industrial housing design and manufacture, Journal of Information Technology in Construction (ITcon), Vol. 14, pg. 110-122, http://www.itcon.org/2009/11*

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.

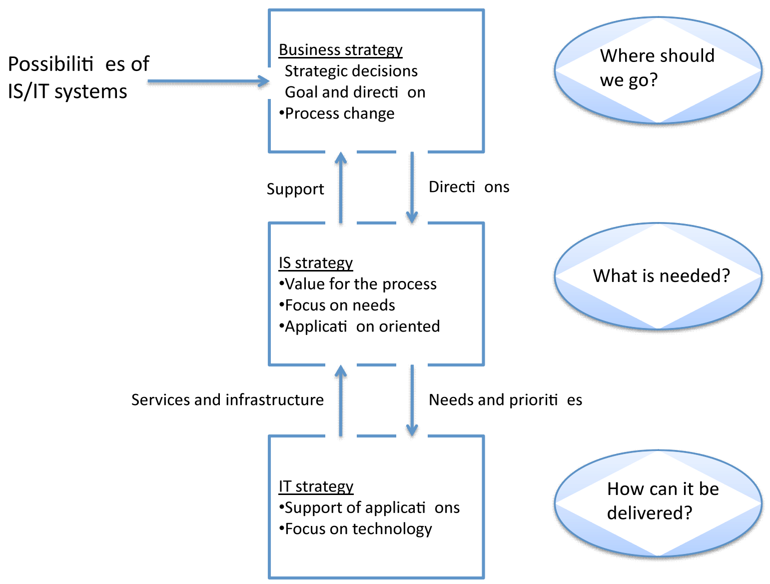

FIG 1: Information system. Adapted from Björnsson (2003).

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.

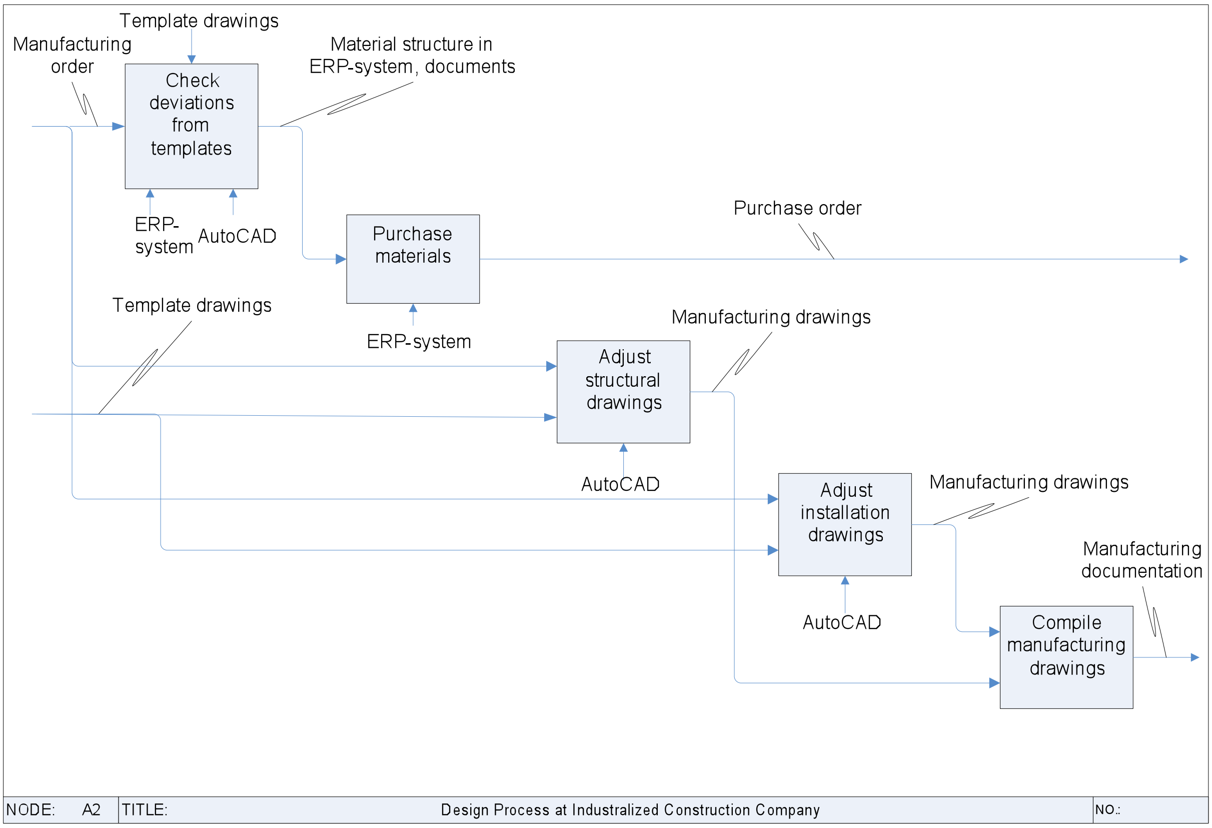

FIG 3: Extract (IDEF0 A2 child diagram) of the design phase from a process model at a Swedish company manufacturing modular houses

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.

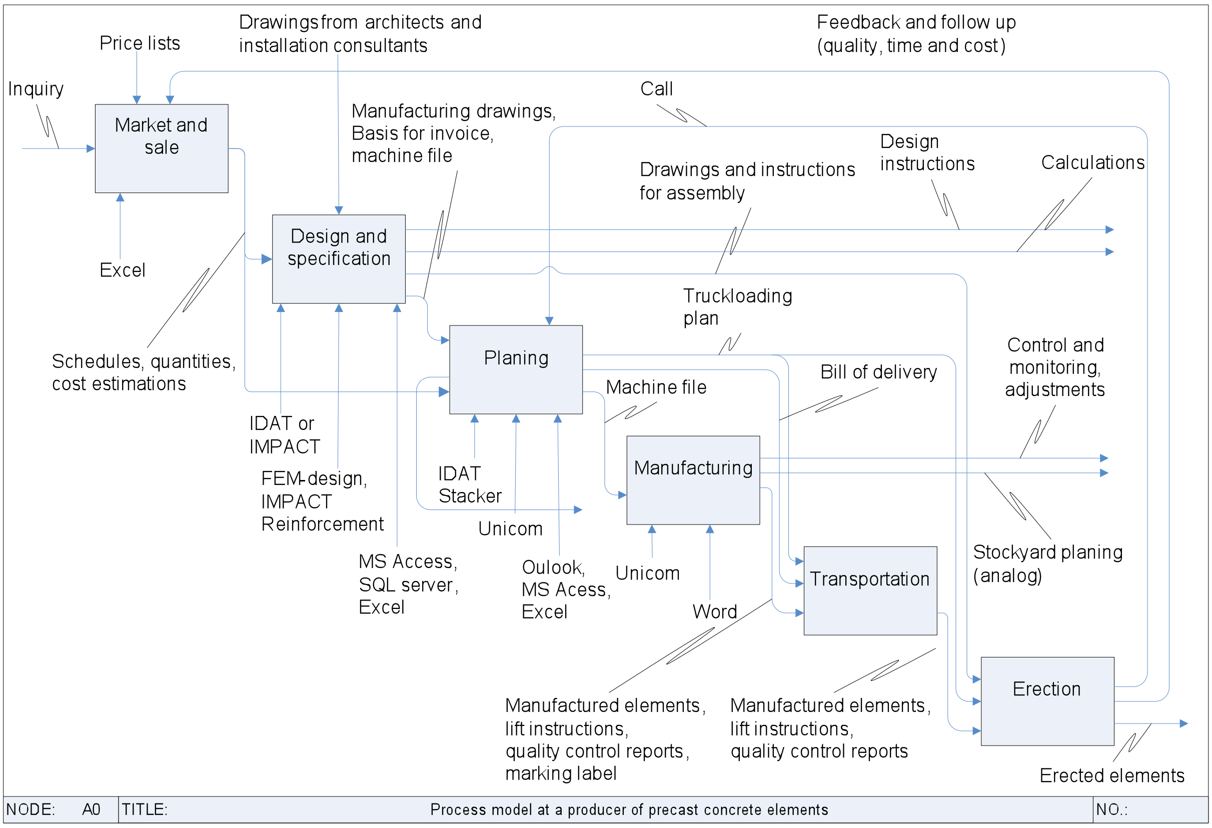

FIG 4: IDEF0 process and information model for the Swedish precast concrete company (element producer 2 in table 1)

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.

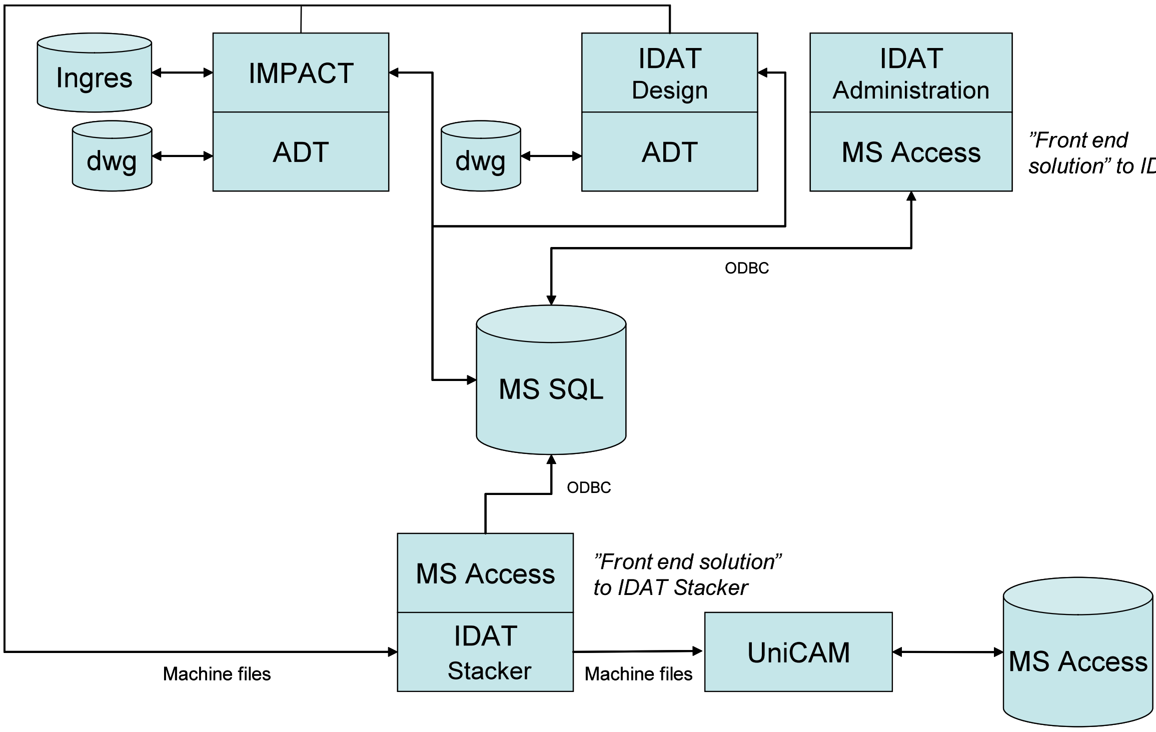

FIG 5: ICT model of the process at the Swedish precast concrete company (element producer 2 in table 1)

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.

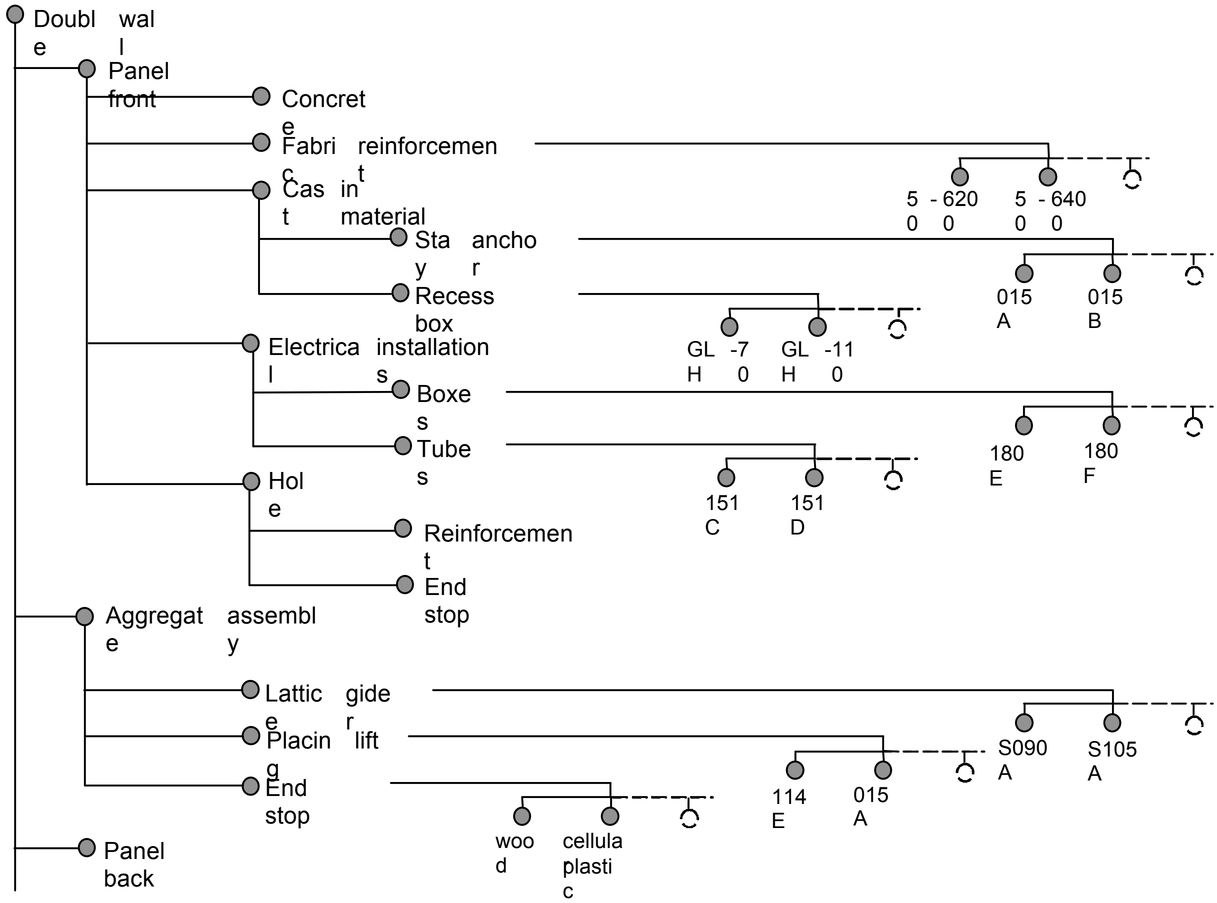

FIG 6: Extract from a product structure in IMPACT of variants in the design of a double wall that could be produced by the Swedish precast concrete company (element producer 2 in table 1)

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.

ACKNOWLEDGEMENTS

For financial support the Swedish Governmental Agency for Innovation Systems (VINNOVA), the Development Fund of the Swedish Construction Industry (SBUF) and Tyréns Ltd. is gratefully acknowledged. This work was performed within the Lean Wood Engineering Competence Centre at Luleå University of Technology, Linköping Institute of Technology and Lund Institute of Technology, all in Sweden.

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