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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 four different views the complexity of the product can be reduced and each view represent the interest of customer, engineering, production and assembly respectively. The analysis shows that the connections between the different view, 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, building product model, product customization*

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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 gap between sales, engineering and production departments often leads 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 and integrated in the design and production of manufactured houses.

On the other hand, 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 it harder to adapt to volatile customers' requirements. Development of modularized product platforms is one strategy for mass customization (Erixon 1998) that often has been used by the manufacturing industry. The customization process needs information about 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). The product documentation in construction industry 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).

This paper evaluates a product family of a Swedish industrialized house manufacturer from two perspectives: (1) how the product is designed, how information is shared and how the product is offered to customers, and (2) what features customers request. The intention is to find a successful form for product documentation that will grasp product information from customer design through engineering and production of the final product. The case study has been performed on a product that is offered at a competitive price with limited possibilities for customization. This makes it easier to see if it can really be managed to foresee customer demands, and if the product can be modularized according to customer needs.

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 the 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 were 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 final workshop is the version published in this paper.

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

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

3. BACKGROUND

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 them. 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 the Industry Foundation Classes (IFC) of the BuildingSmart initiative (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).

According to Björk (1995) the creation of a product model for buildings start 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 the 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 (ISO 10303-11 2004).

3.2 Product configuration

Product configuration is described as an effective mean of structuring products and standardization, but also a way of presenting the product for the customer (Hvam et al. 2008). 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 be resolved:

- 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 have to decide what parts of the product range should be included in a product configuration system. Probably, not all products are suitable for configuration.
- The information needed for the product configuration project has to be collected. This information often resides in documents, CAD files and different types of management systems such as ERP, SCM and CRM. It is also to be found as tacit knowledge of the product specialists within 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 and 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 degrees of freedom of a product:

- *Alternative component models* where the customer can choose exactly one from a set of mutually exclusive alternative components
- *Optional component models* 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 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.

Since the cost of developing a building system is high, system analysis and customers 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 overseen in construction companies; hence customer requirements are treated only in the specific one-off project and often specified by the client in a building program. However, a product platform needs to be adapted to a variety of customers in the targeted market segment to be competitive. Therefore, 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 cusomer needs and requirements early in the process and governs the product development in many ways.

The transformation of customer values and requirements into product properties are often performed by a multidiscipline QFD-team. In traditional procurement systems where different people perform design and construction, the QFD methodology can potentially create problems. The "cross-functionality" approach often used when conducting a QFD, can be difficult to achieve in traditional construction projects where the design, engineering and production planning and execution phases are separated. The QFD methodology can be suitable for projects where 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 surveyed using statistics and customer questionnaires (Eldin et al. 2003).

4. CASE STUDY

4.1 Investigated 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 ready 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 work-force 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 investigated product family

The investigated product family is an affordable house model offered by the manufacturer. It features five alternate 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 turnkey houses to the customers.

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 intension 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 surface materials.

4.3 Product documentation system

CAD is the predominant product description system for the investigated product family. Plain AutoCAD[1] 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 the VBA interface[2]. The production design rules with associated parameters are stored in a 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 linked with customer data. Product related information is consequently kept in two systems, the AutoCAD and MRP system, depending on 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 design rules 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 external users, for example architects, structural engineers and sales agents. It includes 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.

4.4 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. Despite the managements' intention to have relatively restricted customization policy, changes to the original concept are often introduced by the sales department to satisfy customers. 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 teams, 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 family.

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[1] http://usa.autodesk.com/adsk/servlet/pc/index?id=13779270&siteID=123112#

[2] Visual Basic for Applications, http://usa.autodesk.com/adsk/servlet/index?siteID=123112&id=770215

Findings from interviews with sales and engineering emphasize that there are important issues that need to be resolved in order to improve efficiency:

- The product documentation needs to be adapted to the different processes in the company, e.g. in the 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 offer to the customer.

In the next section, we present a conceptual solution of the product documentation issue using different views of a product model of the investigated product family.

4.5 Organizing the product information in product views

Hvam et al. (2008) suggest a methodology based on the representation of the product in a hierarchical structure using the Unified Model Language (UML) [3]. 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 cabinet doors and colors etc, are presented in the customer view of the product. In the production view of the customized kitchen the types of colors and cabin doors is described by 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 application, which is different from the one used on the web site.

The use of process related product views is common in the manufacturing industry and to some extent also in the construction industry. However, the different views in the construction industry are mostly connected to the architectural, HVAC and structural disciplines using drawings and documents, thereby making the integration and coordination between these 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. This would facilitate information sharing in the customization process (Hvam et al. 2008; Johnson et al. 2007).

Accordingly, in our case study the following product views were defined:

- The *Customer view* represents an instance of the product model as 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. This view represents the most important systems for the technical realization of the product features requested by the customers (such as structural, installation etc.).
- 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 the model presented by Hvam et al. (2008) the assembly view has been added to the product views in the case study because this is one essential factor that differentiates the construction industry from manufac-

[3] http://www.uml.org/

turing. The assembly of the final product on site needs to be managed separately, in contrast the manufacturing industry, in general, considering the product finished when it leaves the factory.

4.5.1 Customers view

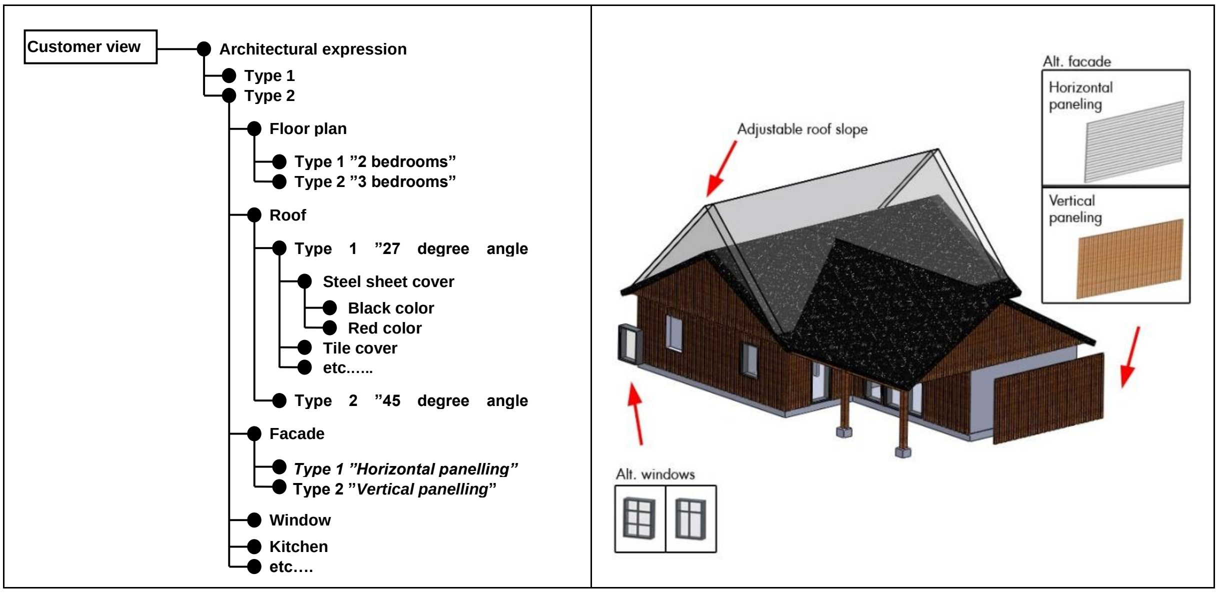
Fig. 1 a) – d) shows the customers view of the product family. The customization options consist of selecting between two types (henceforth referred to as type 1 and 2) of models within the product family. Within the type 1 concept, the customer can for example choose from changing the floor plan to 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. In Table 1 and Fig. 1 the different types of flexibility and alternatives are exemplified by the type 2 house. Table 1 summarizes the flexibility types of the customer views of the product family concept according to Leckner and 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.

The customer product view shows the choices that are important in the context of the sales process. Prominent parameters of this view are (1) architectural expression of the floor plan, and (2) exterior. The details of the structural system, installations etc. are not included because they are not important to 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 engineering and production.



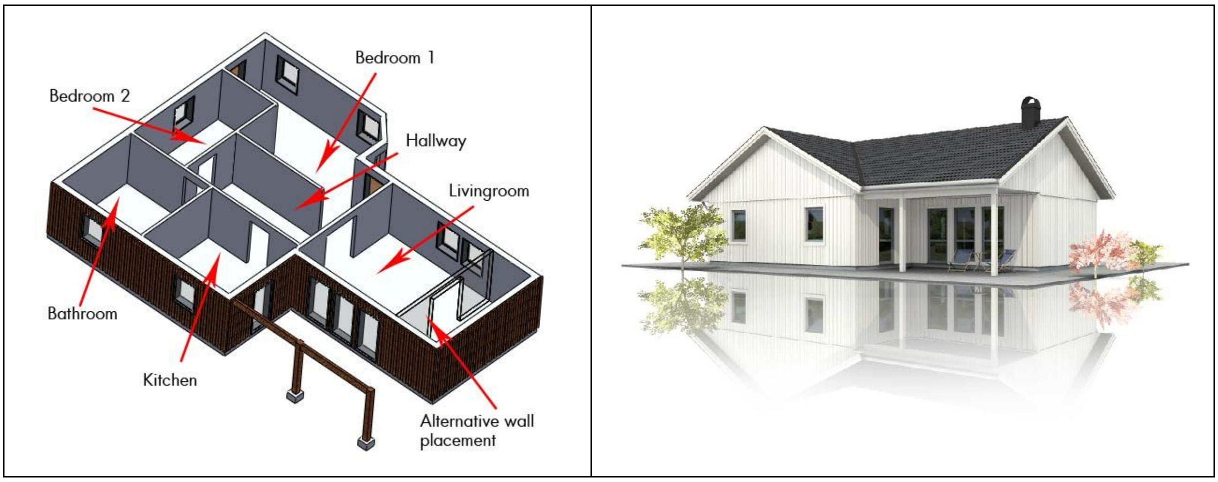
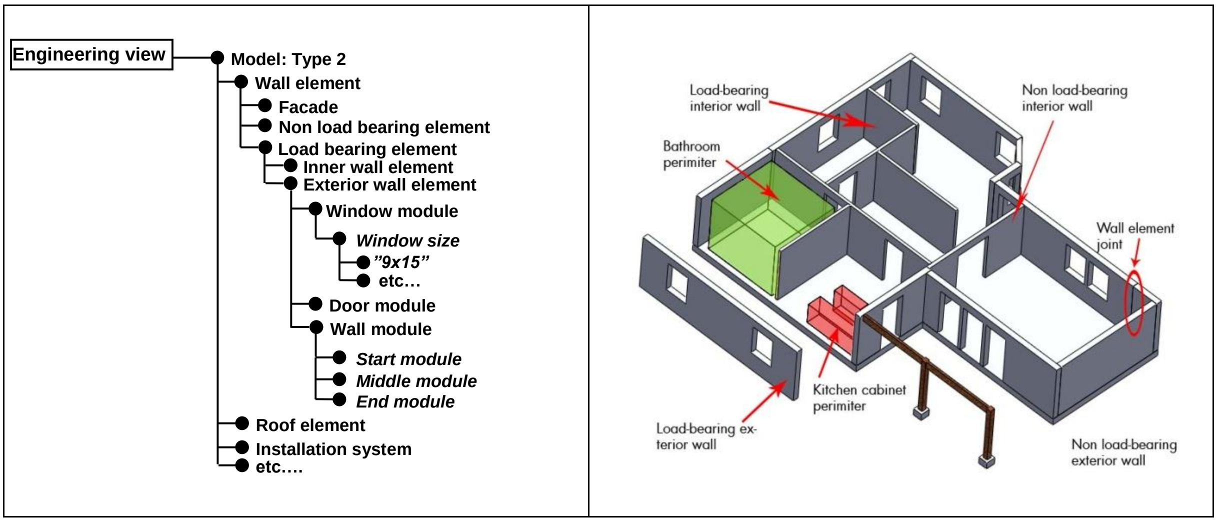


FIG. 1: The customer view of the product family Type 2 alternative.
FIG 1a) shows the product structure, 1b) the façade, 1c) the interior floor plan and 1d) an example how the configured product is presented for the customer.

4.5.2 Engineering view

Fig. 2 shows the engineering view that ensures that the company can technically realize the customers' choices. 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) space objects have been inserted in the bathroom and kitchen as carriers of functional and customization requirements, e.g. bathroom and kitchen requirements on the walls facing these rooms, such as noggin pieces for kitchen cabinets and bathroom gypsum boards that go behind the tiles. Figs. 2c) and 2d) show how a wall can be decomposed or modularized in units that can be reused in product development. The combination of these engineering modules into different wall types in the product must abide the rules of the production system, i.e. they must be able to be produced by the production system.



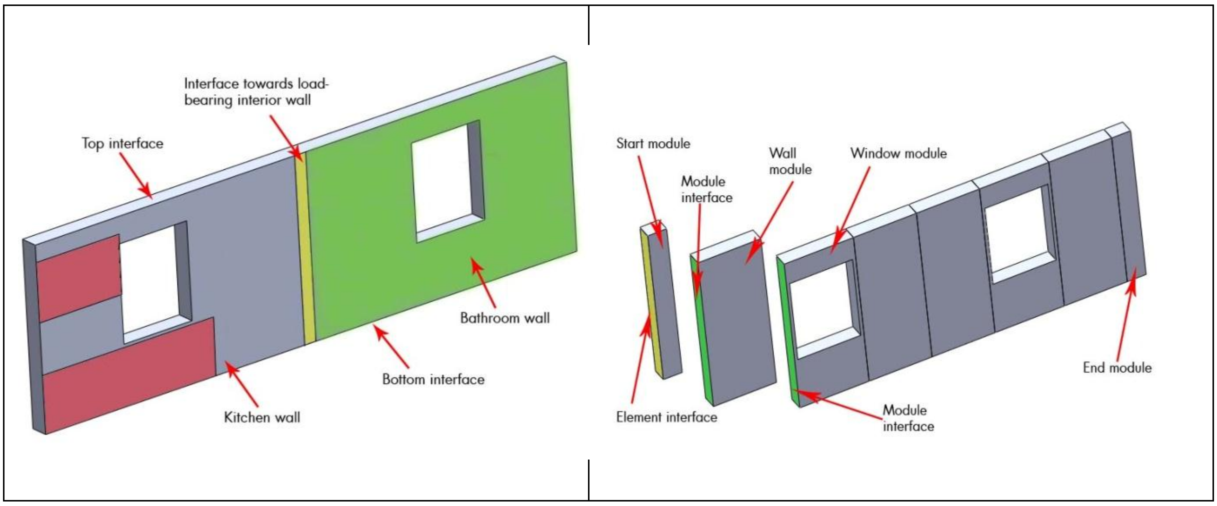
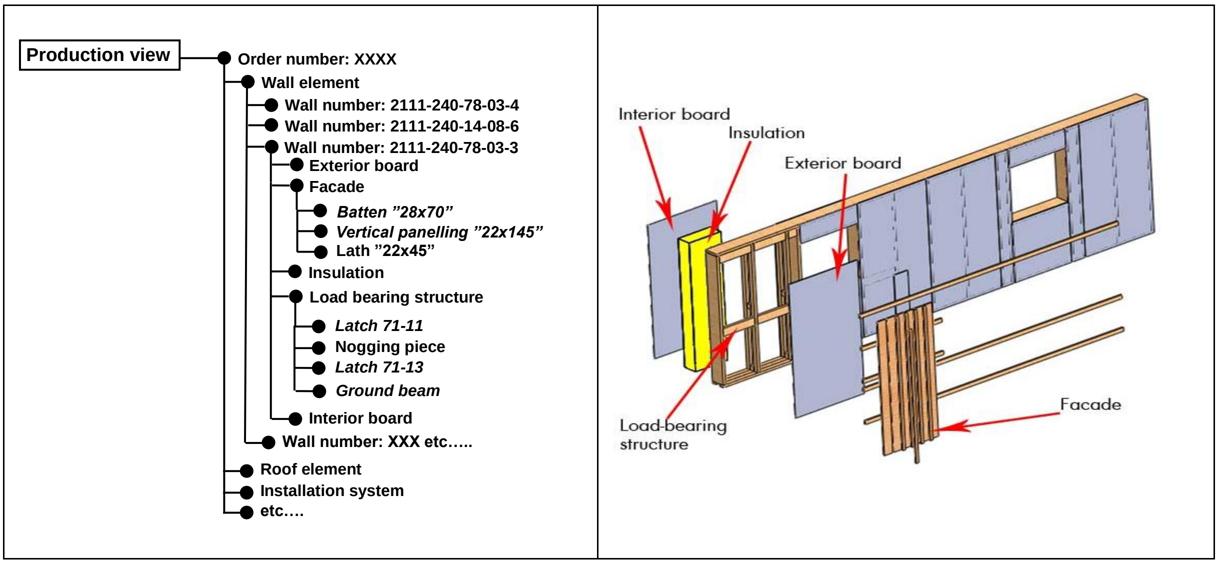


FIG. 2: The Engineering view of the product family type 2.
FIG. 2a) shows the product structure, 2b) the structural view of the interior floor,
2c) an example of a load bearing exterior wall and 2d) its modular composition.

4.5.3 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 the 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 a wall, Fig. 3c) the wall framework while Fig. 3d) contains BOM list and information necessary for manufacturing the wall assembly. CAD applications used in manufacturing industry are often able to connect to various PDM (Product Data Management) and PLM (Product Lifecycle Management) systems, but CAD applications in the AEC industry are seldom used together with PDM or PLM systems.



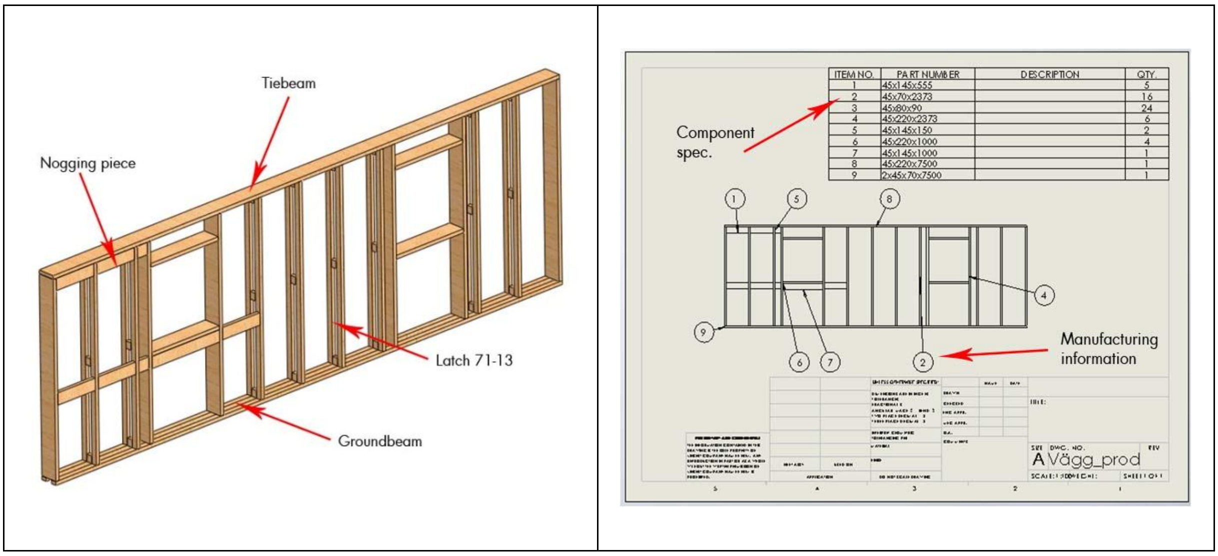
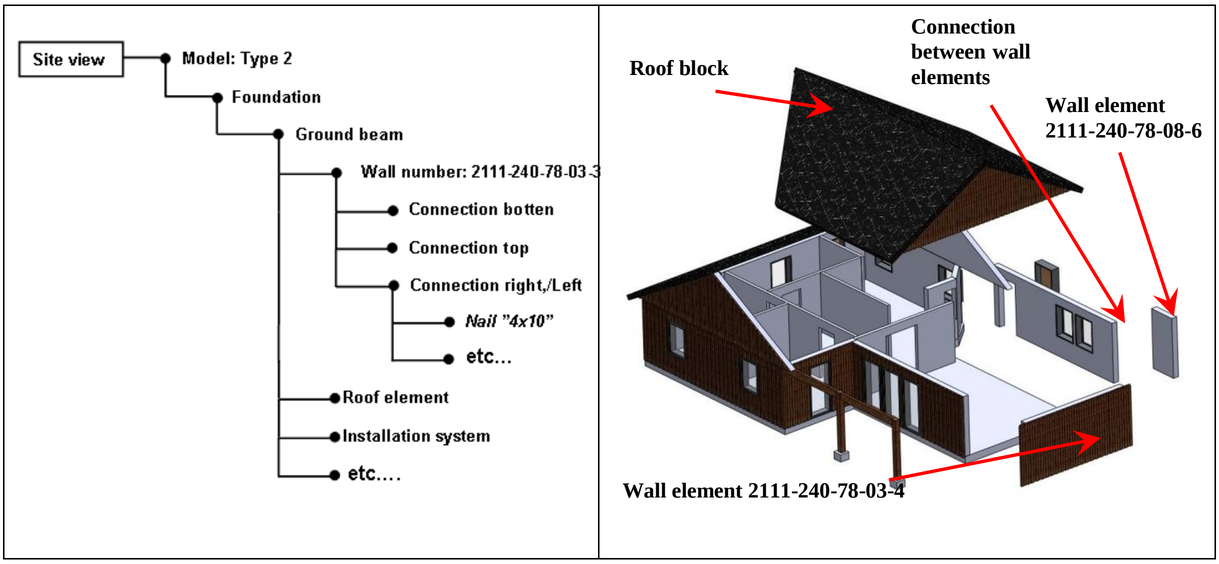


FIG. 3: The Production view of a customized order.
FIG. 3a) shows the product structure, 3b) an exploded view of the highlighted wall element, 3c) the framework of the wall and 3d) its BOM list and manufacturing information.

4.5.4 Assembly view

Fig. 4 shows the assembly view that provides information on how the product will be assembled on site. Information needed in this view is assembly instructions, the order in which the prefabricated elements such as roof blocks and wall elements needs to be delivered to the assembly site and the 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 connections 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 workflow and the possibility to combine with 4D visualization (Jongeling and Olofsson 2007).

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.



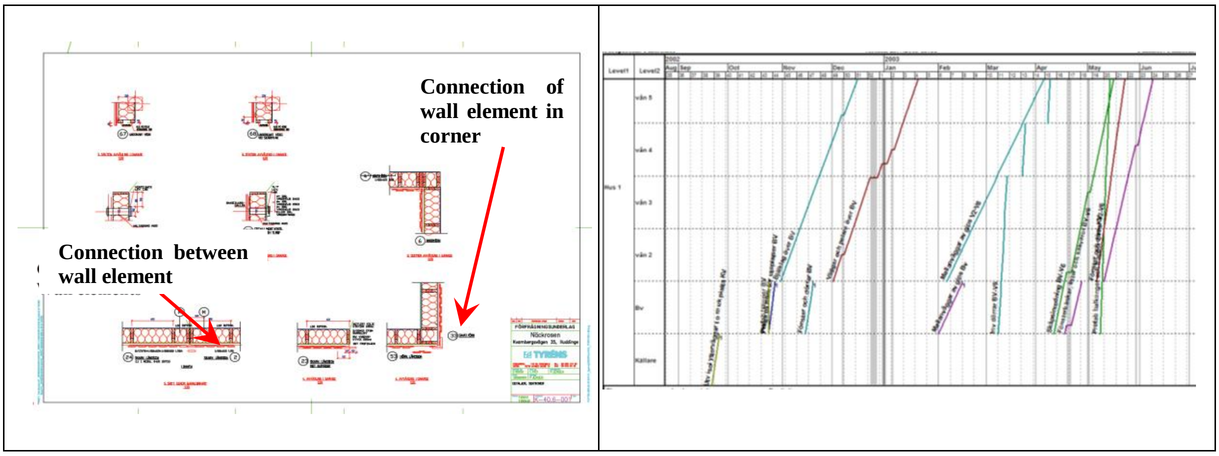


Figure 4: The Site view of a customized order.
Figure 4a) shows the assembly product structure, 4b) an exploded view of the assembly structure, 4c) assembly drawing of connections and 4d) the assembly schedule expressed in a flow-line diagram.

4.6 Customer Requirements

According to the company the house models are targeted towards families looking for a customizable house with relatively high standard regarding materials and construction but not with too many other choices, see possible alternatives in Table 1. Actually, the studied case company refers to itself as an engineering company that focuses more on the demands from the production department than demands from the customers. However, if these models are to be successful on the market, the 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 2008). The Internet survey, performed in 2008, received about 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 compared with the product offers of the product model (Horsman 2008)

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 build 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 kitchens, etc, are among the top alternatives where customers indicate a relatively high willingness to pay. In a survey undertaken in Holland “type of kitchen” also ended up as the most important customization property (Hofman et al. 2006). These types of customer surveys provide valuable information for customization options for the house manufacturers.

5. ANALYSIS

5.1 Organizing the product documentation

Less complex information models of the reality that are better adapted to working processes probably have a better chance of success (cf. 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 processes respectively. 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 how different views of the same product intervene with each other, for example the chosen kitchen type in the customer view will affect the engineering view with how the noggin pieces will be placed, but also the production view in the actual production of the wall element. This will also affect the assembly view when assembling the kitchen on site. The transformation of information is therefore critical to ensure that ad-hoc solutions are kept to a minimum.

Today, experiences from earlier projects are seldom documented; they exist only as tacit knowledge in the 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, a 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.

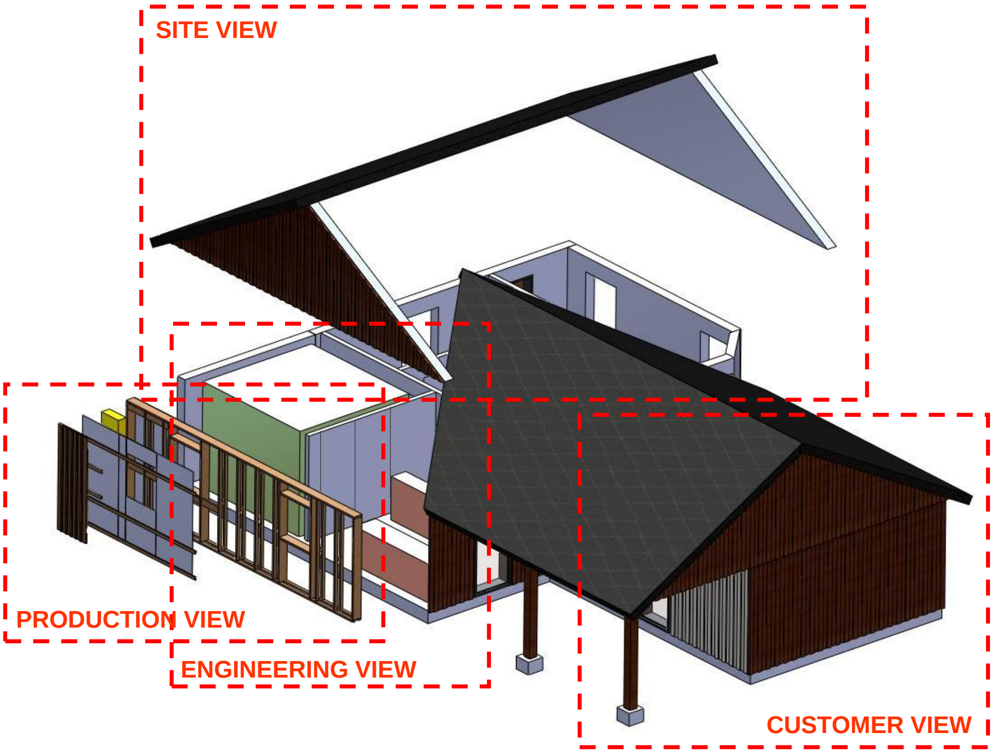


FIG. 5: The separate views of the same product and how they overlay each other.

Today, there exists a multitude of product modeling technologies and systems that can manage complex products. However, most methods and tools are still limited to support the design, development and production only of single products (Claesson et al. 2001). Often only the geometric description of products generated by CAD systems is managed directly (Sudarsan et al. 2005). Instead, 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.

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 the 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

An order is verified against a checklist which describes the customization rules (constraints). This checklist contains detailed information of the house to ensure that products can be efficiently manufactured, giving 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 provide 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 indicate that the link between customer view and the other views (engineering, production and assembly) is 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 solutions 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 constrains 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.

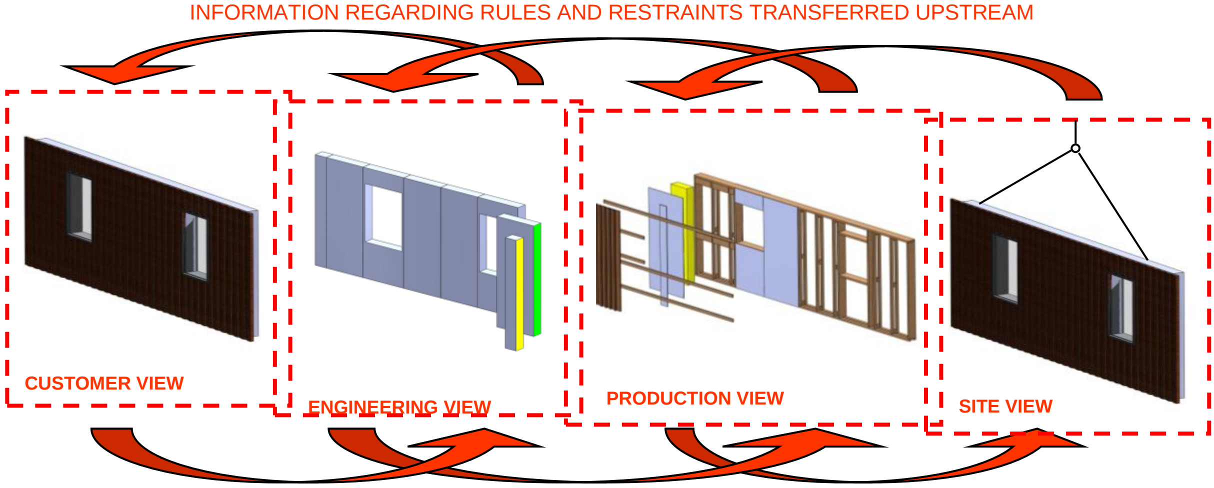


FIG. 6: The connection and integration of information between the separate views

6. CONCLUSIONS

Product modeling is a suitable technology to describe the product structure of modular houses. It gives the manufacturer the opportunity to get a view of the entire product range. Creating adapted views makes the product structure less complex to implement and easier to split in more than one release. The integration between the different views consists of information transferred downstream from the customers view to the engineering, production and assembly views. The rules and constraints of the building system are transferred upstream from the assembly, production and engineering views to the customers view and hence define the customization limits of the product family.

The presented 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 changing customers’ expectations increases the risk for ad-hoc solutions propagating to manufacturing and assembly on-site with considerable higher costs as a result. Eventually, the product will become harder to sell. It is also evident that the ICT-tools used to create and manage the different views should be *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 a key to future development and customize-to-order configuration, because it provides an explanation model of the information transfer needs and it also provides a good visual overview of the goals set out to accomplish by a company in terms of information management. Using the four views will give companies a structure for how to plan and organize information transfer.

However, there are some evident barriers for companies who want to implement information management systems. Currently there is a lot of tacit knowledge within the studied companies that needs to be formalized before it can be used in an IT system. Several companies also need to go through a process of unifying their view on product information within the company, so that they have a common ground to stand on when taking on new challenges. Another issue is that the general level of IT maturity is lower compared to other industries. Regarding the choice of system there are no specific systems for integrating information in this relatively small sector, which means that custom development is one probable solution. Going forward companies need to be prepared that regardless of what system they decide to use, it will probably need customization to work with their specific needs and processes. This implies that the company has to be more involved in the development or customization, the right competence for this might need to be built up before a project can be initialized.

The main lesson learned from the studied project is that it proved beneficial to use the presented four views as a way of visualizing the information flow from customer requirements to a turnkey-ready house. This approach also showed useful as an analysis model – by using the views to assess how well integrated information transfer is achieved within a company. We have also learned that a mismatch between the technical platform and customer requirements will lead to more ad-hoc customization downstream, which in turn leads to a product platform that might grow without control. Instead, new product features should be introduced as a result of strategic decisions that are aligned with the overall company strategy.

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