Managing system products: A case study of prefabricated building parts

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This paper examines the business of supplying prefabricated system products, i.e. multi-technological building parts which can be cost-effectively delivered in variable designs. Certain aspects of construction work support the spread of such products, including an often mentioned complexity on construction sites and a prevalent tendency towards costly and cost-escalating construction projects which system products have potential to reduce. By enquiring into the experiences of a Danish company supplying such a product, we exemplify how they can meet perceived needs in construction. We also discuss how certain factors in the construction industry apparently complicate the supply of system products. This point particularly concerns a tradition for decision-makers in construction projects to design building parts and then have them custom-built, implying that these actors are not used to facing a need for considering the limitations and demands of system products. The study shows how a perceived need to adapt products to individual construction project features and preferences complicates textbook modularity by suggesting 'pick and choose' rather than 'plug and play' opportunities. We conclude by sketching out the benefits and shortcomings associated with defining and adhering to a precise modular architecture of system products and with adopting a less well-defined product structure and instead adapting the product to each project.

Introduction

When commenting on the general situation of the Danish construction industry, a range of actors have, during the past years, called attention to a notable room for improvement of competitiveness and preparation for future challenges. In contemplating various initiatives to develop the industry's practices, increased industrialization is currently receiving considerable attention as a potential means of bringing in efficiency to the potential benefit of both customers and the firms carrying out construction work. Industrialization can find expression in among other things the factory-like production of so-called system products to be implemented in buildings. These products have a certain appeal because they employ modular architectures which enable suppliers to achieve production-wise advantages while also offering customers some variety and customisation through individual configuration of the elements forming the products. The hypothetical relevance of such products in the construction industry is seemingly manifold, and theoretical advantages of modular architec tures in general have already been documented expansively. Still, the great potential of system products has apparently not yet been fully realized – recent debate on the topic asks for more practical initiatives and several steps are taken to explicate the benefits of system products and thereby to encourage practitioners' commitment to them. This ongoing effort suggests that supplying system products to the construction industry and implementing them in concrete construction projects is not a straightforward matter; it may be associated with considerable managerial and practical challenges. In the effort to explore such possible challenges and to advance our understanding of system products further, this paper presents a case study of the experiences of a Danish company providing a specific type of variable, prefabricated building parts to construction projects. Through an inductive approach, the study seeks to identify the case company's reflections and experiences with the system product and thereby to convey insight into the deliberations and compromises implementing such products in the Danish construction industry can cause.

Setting the scene

The current debate about industrialization of the Danish construction industry[2] focuses on standardized products and rationalization of establishment processes, and it involves large-scale building concepts as well as smaller, so-called system products defined as follows:

'A system product is a multi-technological complex part of a building, developed as a completed modular and variable product.
The system product is developed in a separate product development process based on the principles of integrated product development and "developed for life cycle" – which means preparation of its marketing, delivery process and servicing.
The system product is developed for mass customization. The product is developed with a room for variation within which it can be configured and individualized for each construction work.'
(Mikkelsen et al. 2005: 3, our translation).

Examples of system products are integrated façade solutions, garrets, prefabricated kitchens, prefabricated bathrooms and multifunctional ceiling solutions. This definition builds on an understanding of "modularity" as the development of modules employing some common characteristics which can be varied in order to meet customers' needs. The decomposition of products and the standardization of components' interfaces is what theoretically enables modularity to ensure such individual solutions (Sanchez 2000: 614). Integrated product development means that developers make decisions which have consequences in the rest of the product's life cycle. They therefore attempt to create a product which is appropriate in configuration, use and maintenance (Mikkelsen 2005: 56). Finally, the term "mass customization", expresses an intent similar to that of modularity, namely to develop a product programme which matches different customers' different needs and doing it in a cost-effective way by ensuring some common features in construction, production, installation etc. (Mikkelsen et al. 2005: 20; Pine et al. 1995: 105).

The benefits of employing more pre-manufactured system products, as presented by various interested parties in the construction industry, include:

- Faster, less expensive project realizations through efficiency enhancement of establishment processes.

[2] E.g. http://www.arkitektforeningen.dk/aa/4908CD66-CCF6-4963-A26F-C8600F7ECEE7.htm; Beim 2005; http://www.ebst.dk/industrialisering; Erhvervs- og Byggestyrelsen 2006: 16; www.industrinetvaerk.dk/15242

- More processes can be carried out indoor under more controlled conditions than are available out on the site. This reduces the dependence on weather conditions and it may result in a more homogeneous quality.
- Reduction of an overwhelming complexity and need for coordination in construction projects through the encapsulation of processes in one delivery and the resulting fewer actors on the site.
- Suppliers take responsibility for installation, maintenance and adaptation of the systems.
- A flexible building architecture enabled by sub-systems made up of replaceable components.
- Reuse of modules permits actors to utilize experiences gained in prior projects rather than reinventing the wheel in every project.

(Based on By & Byg, Statens Byggeforskningsinstitut 2003; By- og Boligministeriet 2001B; Mikkelsen et al. 2005; Thomassen 2005; Thorsen 2005; http://www.ebst.dk/industrialisering).

This brief review shows that system products have the potential of meeting several well-known problems in the construction industry. As a relatively recent phenomenon in the debate, however, our understanding of them is still not fully completed. In particular, it is not clear whether the construction industry only presents conditions propitious for their implementation or if there are also conflicting factors complicating the business of supplying system products. Insight into practitioners' positive as well as negative experiences may elaborate our understanding of system products in a Danish context, and also implicitly our understanding of the Danish construction industry.

As indicated above, the issue of industrializing the construction industry through use of prefabricated system products is closely related to that of modular product architectures, understood as initiatives to break down products or processes into smaller, interchangeable units as a means of achieving efficiency without ignoring customers' varying needs (Baldwin & Clark 1997; Sanchez 2004). Theoretical advantages of pursuing modular product architectures have already been elaborated extensively (Garud & Kumaraswamy 1995; Sanchez 2000; 2001; 2002A; Sanchez & Mahoney 1996), and they have been documented in specific product contexts, particularly in the area of personal computers (Baldwin & Clark 1997; Langlois & Robertson 1992). An inspection of this literature specifies the advantages of modularity to include the achievement of scale economies while meeting various tastes and needs, a reduced need of managerial coordination, facilitation of innovation and development to meet changing market conditions as well as clarification of organizational knowledge. Research on modularity also includes a continuous investigation of the further potentials and limits associated with modular product architectures. This trend has led researchers to explore the relations between modularity and a variety of managerial concerns such as organizational knowledge, coordination (Brusoni & Prencipe 2001), supply chains (Lau & Yam 2005) and the ability to develop or alter product components and architectures (Chesbrough 2003; Galvin & Morkel 2001; Staudenmayer et al. 2005). As diverse as the focus of this research is, together, it provides the insight that modular product architectures raise considerations for more than the elements they are intended to design and that the wider implications are not always directly proportional to modular product architectures. The topic of modularity as a strategic and practical tool is, however, not fully exhausted; particularly, the managerial challenges related to presenting and implementing modular product architectures as sub-systems of much larger and varying systems, like for instance entire buildings, are not clear. In construction work, a balance between systematization and standardization on the one hand and architectural variety and innovation on the other always needs to be defined (Lund 2005: 71-72). But when "(…) standardization is a key concept in modularization" (Chen & Liu 2005: 773), how are modular product architectures implemented in circumstances of such continuing consideration of trade-offs between internal standardization and adaptation to varying settings? Can suppliers of system products maintain a set modular architecture and at the same time ensure the meeting of individual needs? These contemplations provide the theoretically-based starting point of our enquiries.

Research ambition

It is the present study's business to identify managerial rationales for and challenges stemming from the attempt to handle complexity and facilitate efficiency in construction projects by developing and providing system products. We do not consider further discussion of perceived barriers to these products redundant as indicated elsewhere (Mikkelsen et al. 2005: 42-43); rather we find it appropriate to elaborate our knowledge of the barriers and their occurrence and therefore permit ourselves to dwell at the issue.

Together with an expected practical advantage of enlarging our understanding of managing system products, the study builds on a notion that managing modular systems intended to be parts of larger, rather unsettled, somewhat externally controlled systems, in this case building architectures, may be different from handling more self-contained systems such as e.g. hifi systems (Langlois & Robertson 1992) or cars (Baldwin & Clark 1997), although the structural contexts of those artefacts should probably also not be considered constant or negligible. One may envisage that the Danish construction industry eventually develops as the American equivalent, i.e. that it becomes characterized by a widespread appliance of industrially manufactured construction components through the breakdown of buildings into system deliveries (By- og Boligministeriet 2001B: 14; Erhvervs- og Byggestyrelsen 2006: 7). Indeed, it may only be a matter of time before a more dominant design of building architectures and sub-systems will emerge as in the passenger airplane industry (Tushman & Murmann 1998) or the car industry, since construction has similarities with such assembly sectors (AEGIS 1999: 6) and since '[t]here are no intrinsic, technical reasons why the building industry should not be as automated as the car industry' (Woudhuysen & Abley 2004: 184). Another conceivable scenario is that many construction projects will maintain a considerable degree of project-specific custom-making together with use of traditional building contractors and thus remain the rather complex and unsettled context in which some system products are implemented. As it is not the concern of this study to forecast the most probable industrial development, we will not dwell at the likelihood of various scenarios. Instead, we focus on the experiences of companies providing system products in the current changeable context, which we expect to face challenges diverging from those associated with more independent modular products, necessitating other skills of manoeuvring when designing, developing, marketing and delivering. By examining what it takes to facilitate sale and implementation of a specific system product, we intent to identify managerial rationales and perceived hurdles for this business.

Clarification of the terms used

Before presenting the research further, it is worth emphasizing that we perceive the united physical elements of the case company's solutions to constitute functional systems which are themselves sub-systems of larger systems; the entire buildings. The system product is a sub-system composed of smaller parts which we interchangeably term components and elements. Such elements of sub-systems may also be viewed as sub-systems on their own (Miller 2001: 20; Tushman & Murmann 1998: 330) in that each of them organizes connected sub-components. However, this degree of detail is not the primary focus of the study at hand.

We perceive buildings as unstable product architectures in that the decompositions and interface specifications of their sub-systems are not standardized and settled in the Danish construction industry: No widespread industrial standard design rules prescribe how all sub-systems of a building should be physically attached to each other, where every one sub-system should be placed in a building or how much space each of them is allowed to occupy. We are interested in the case company's experiences with implementing system products in this less than stable context.

Research design

The study at hand preserves a focus on the outlined objective by extracting and describing the experiences of the case company with introducing and providing its system product for Danish construction projects. Specifically, we will address the following research question:

How do the conditions in the Danish construction industry support and complicate the supply of system products?

We expect that narratives of what this company's employees and managers do in order to enable support to its system product, including which compromises they consider necessary, will provide insight into the current conditions for system products – what is in favour of them and what hinders or complicates their spread. Given the character of the research question, the absent need for controlling behavioural events and the focus on relatively recent events in the case company, we consider a case study an apposite research strategy (Yin 2003: 5)[3]. Furthermore, the analysis represents an exploratory case study meaning that we attempt to draw out practical challenges and perceived barriers from the case. This is deemed relevant given the open-ended research question and the fact that no particular challenges are self-evident beforehand; rather we intend to identify indications as to what kind of issues associated with system products might need managerial and academic attention. Potential challenges may materialize in various parts of the involved parties' dealing with the systems. To facilitate a broad, initial insight into these potential challenges, we include in our enquiries some main activities which are expected to precede delivery of modular products in general: Defining the architecture, designing configuration of individual systems, sale, and establishment of the systems. By examining which issues preoccupy the company's employees during those respective activities, it is the intent that this study covers the subject of implementing system products in Danish construction projects broadly.

To maintain the exploratory intention, we deal with the outlined issue by seeking answers to two very open-ended sub-questions. However, acknowledging the aforesaid initial expectation that the manageability of modular architectures may differ from theoretical accounts when they are to be parts of larger, unstable systems, these sub-questions are assigned more concrete yes-or-no ques

[3] Yin differentiates between contemporary and not-contemporary events. The events studied here spread over a period from 2002 till today. Although the earliest of these events are not taking place right under our eyes, they represent recent episodes fresh in the employees' memory, and their outcomes are expected to have an impact on the employees' on-going handling of the company's solutions. A case study is therefore considered an appropriate means of understanding these events together with current ones.

tions. The additional questions are derived from hypotheses found in general modularity theory, and they are attempts to operationalize the sub-questions while avoiding an inappropriate preliminary guessing of which challenges the case company actually meets. In recognition that diverging perceptions and effects of modularity exist (Baldwin & Clark 2000: 90; Miller 2001: 47), we compare our findings with hypotheses derived from diverse modularity theory including engineering, product development and organization literature which focuses on various specific as well as general applications:

1) **What are the rationales behind the attempt to develop and implement the system product?**
- Is a system product strategy pursued as a means of achieving benefits theoretically associated with modular architectures such as the ability to manage complexity, activities and resources and / or rational creation of variety and product innovation?

2) **Which efforts does the case company make to enable implementation of its prefabricated system product in construction projects? (i.e. which challenges are associated with this business?)**

A. Does the modular structure of the system product enable the company to cater to diverse tastes and needs through different configurations?
B. Is planning of individual projects characterized by a ready configuration, i.e. ‘plug and play’ of available and compatible components?
C. Does realization of projects pass off as simple assembly of standardized modules / components?
D. Is product development organized as decoupled processes where independent designers devise new components, guided by the design rules of the product architecture?
E. Can the company, with this system product, respond readily to changing market demands?

Introducing these theoretically-based questions is by no means an attempt to evaluate the worth of the underlying theories, since we are aware that several of these have been developed with industrial products, not construction systems, in mind, and that systems for construction projects cannot necessarily be mindlessly put on the same footing as such products (By- og Boligministeriet 2001A: 13, 26). Rather, it is the hope that by matching the company’s experiences up to modularity theory, we can extract interesting insight into the management of system products in the Danish construction industry.

We have chosen to approach the theme by studying one company whose prefabricated, standardized and yet individualized construction product represents an attempt to present a system product and thereby achieve industrialization benefits. It sells the system product to both new building and renovation projects, and although the processes of delivering to these two types of projects differ noticeably, we include both of them in our analysis as the products in both cases reflect the definition of system products and because they, with their different processes reaching similar end results, have the potential of providing different insights into the implementation of system products.

Gathering of data

With our case company's system product as the pivotal point of our study, we employ multiple sources of evidence to ensure the quality of the research:

First, a number of documents concerning the responsible department in the organization, its products and concepts as well as its participation in concrete construction projects are included in the work. Although they have all been produced for purposes other than this case study, available documents such as brochures, advertisements, webpage articles and descriptions of prior projects are valuable here in that they provide insight into the case and direct attention to potentially relevant courses of further investigation.

Second, interviews with employees and managers from the department constitute an essential part of our data, and we include representatives responsible for various activities – employees involved in product management, sale, establishment of the building parts in question as well as general management of the department. In addition to providing insight into the various stages of working with the system as identified above, the inclusion of several informants also enables avoiding personally biased data. A flexible interview plan is initially carried out and handed over to the case company on which basis the relevant informants are identified. Informants are thereby briefly notified about interview topics prior to the meetings on the assumption that their preceding deliberation of the topics may be to our benefit although we do not want them to consider specific interview questions beforehand as this may hinder the preferred spontaneous conversations. Interviews are carried out in a period of three months lasting from the end of November 2005 till the end of February 2006 during visits on the company's site and on the site of an ongoing project. They are carried out as primarily open-ended conversations meaning that we ask informants to elaborate on the company's development, designing, sales and establishment efforts – i.e. to describe the general state of affairs as well as specific events relevant to the particular topics. The meetings with our informants, which in the main last one and a half hours, are recorded and subsequently transcribed.

Third, observations of the system products and the way they are handled also provide a valuable source of data. During visits on the head office, the company's showroom and a current project, informal observations of fragments, prototypes and installation of concrete variants of the system product are made, which enable a relevant insight into the subject of our enquiries and thus contribute to our understanding of the phenomenon being studied.

Analysing the data

Although we thus seek to maintain focus on our theme through these relevant sources, our study will not result in broadly applicable generalizations. Such results are expected to require more comparable empirical studies and a longer time-horizon than is available here and may therefore be the object of future studies. Our intent to identify and understand the conditions and hurdles facing a company providing system products implies that we do not develop objective means of determining the relative importance or magnitude of various challenges. We attempt to identify challenges based on what our informants present as complex, time-consuming, problematic, unexpected or demanding issues. When these challenges are less than clearly expected based on our theoretical hypotheses, we attribute them to the concrete circumstances in which the company's products are positioned and thereby hope to provide a preliminary insight into the implementation of system products in the rather unsettled context of building projects. It follows that we do not identify objective criteria for assessing the success with which the study has answered the research question. Because of the opening character of this research, we consider the research question sufficiently addressed when two things are accomplished: First, the yes-or-no questions inferred from modular product architectures in theory needs to be clearly answered and potential discrepancies between theory and the case company's experiences described with regards to their appearance and their associated managerial challenges as expressed by informants in the company. Second, any other apparent hurdles associated with the management of the system product brought up during our interviews, which are not covered by our hypotheses, have to be reported here for the sake of the intention of providing clarifying and inspiring insight into the management of system products.

The case

In the following, a brief presentation of the case company and its products is offered before we discuss our empirical findings.

The organization has a long history of manufacturing solutions for other purposes than construction work. Given a perceived need to spread the company's risks by aiming at more markets, a department was found in 2002 with the intention of carrying the pre-fabrication strategy further by developing a range of products for construction projects. The company has thus, since well over three years, broadened out its business area to include solutions for construction projects. This has resulted in the introduction of various, more or less complex, concepts. The products are manufactured partly on the company's own factories and partly by a cooperation partner located abroad. A team of employees based in the Danish headquarter manage the administration, product and project portfolio and sale, and sales agents abroad take care of sale to foreign markets. A number of craftsmen handle the installation of the products in concrete building projects.

Characterizing the system product

The product studied here is delivered in large batches to projects requiring numerous similar solutions. Internally in the case company, it is considered a main business area which is expected to facilitate the familiarity of the company and ensure its establishment in the Danish construction industry.

The product reflects several aspects of the reported definition of system products, which implies multi-technological, complex, modular, variable construction products developed for mass customization. All variants of this product consist of the same primary structure, which we will here designate "the framework" of the products. The elements forming the framework are produced internally and by a cooperation partner who has marketed similar solutions for years. In addition to the framework elements, the product comes with numerous, multi-technological equipment and installations. These last-mentioned elements are, based on customers' individual preferences, purchased from national and international suppliers and sent to the production facilities where they are integrated with the framework elements. In addition to thus being multi-technological, the product represents modularity in that both the framework and inserted parts are systematically broken down to some basic elements and that several of these elements are represented by a selection of recombinable variants. One informant illustrated this by comparing the product with Dell computers:

“It is in fact similar to what we do. We have projected a lot of solutions which enable (…) you to make your own decisions. And then we make sure that what we insert for you is prefabricated. So the difference is not particularly big, except that the one thing is a computer and the other is a [XX]. The behind lying line of thought is in fact the same”.

Some of the elements in this product can be substituted without much difficulty due to fixed standards – for instance, there are surfaces in different materials and colours to choose among and some equipment can relatively easily be substituted with alternative ones since they all adhere to a common industrial standard. Additionally, the product is variable in that some elements can be added to or left out from the system product according to customers’ varying wishes. The materials and construction of the framework elements, on the other hand, always remain the same and can thus not be exchanged at one’s discretion. Still, they reflect the system product reasoning because they, in accordance with accounts of mass customization, efficiently meet different needs through the maintenance of production and installation processes: The adaptation of their sizes and forms to specific projects is rather uncomplicated due to automated fabrication. Moreover, since the company adheres to the same interfaces between these framework elements, they are attached through similar processes in all projects. It follows that the product concept has room for variation within which solutions can be configured and individualized.

As mentioned, the case company delivers this product to both renovation and new building projects. The end products are similar, but the implementation processes differ somewhat which can be summarized as follows:

Renovation: The framework elements for products used in renovation projects are fabricated abroad by a cooperation partner who has provided a similar system product for its home market for several years. The original system has been modified in that certain equipment approved by the Danish authorities has replaced the original parts in order to make the products comply with national requirements and thereby to be able to sell them here.

The breakdown and spatial specifications of the framework elements in renovation projects are rather dependent on the characteristics of individual jobs. Particularly, the sizes in which these elements are produced depend on the physical means of access in the specific building projects, since the elements have to be carried into the already existing buildings. They are also limited by the pre scriptions in the ‘health and safety at work act’ of the maximum weight of elements to be carried by workers. For these reasons, the case company sometimes decides to divide framework elements into pieces to be clamped together on the site. Based on individual customer preferences and the structural character of specific orders, the producing partner thus delivers the elements making up the primary structure of the system product in pieces which are brought to the site on pallets. Here, workers carry the elements to the appropriate placement in the building and insert them as well as the externally devised equipment to make up the desired solutions. For each unit, approximately 14 days are spent on site-specific installation and testing activities.

New building: Products used in new building projects are manufactured at the case company’s own factory. After production and assembly of the framework elements and insertion of the requested purchased equipment, the products are transported as completed packages to the building site. In opposition to renovation projects, new building projects enable the system products to be craned into their destination in the building, because they arrive at the site at selected points in time of the construction process before buildings have been sealed. On the site, the company’s own fitters install the system products and test them, which takes less than a day per unit.

Rationales

As appears from the case description, our case company's system product concept represents a means of replacing on-the-site construction with factory made, installable solutions. In that sense, it also represents a replacement of the pure customization, which involves personalizing basically all stages and which is common in construction work (Lampel & Mintzberg 1996: 26), with some level of standardization. In the business of renovation projects, this represents a notable departure from the traditional approach, because usually, renovation of this building part is carried out by numerous skilled craftsmen on the site. In new building projects, the difference between the company's concept and existing alternatives is smaller; several of these projects have, already before this company entered the construction market, made use of some kind of set package solutions provided by competing firms.

The rationale for presenting the outlined concept of combinable prefabricated components is based on an assumption that construction may be carried out more efficiently than is possible through full customization while utter standardization is not an obvious choice given the varying needs of customers and a perceived improbability that a completely set product design would be generally accepted. The intended benefits of the case company's approach to providing these prefabricated system products include:

Cost savings: The system product concept enables our case company to offer customers considerable economic savings compared to traditional, competing alternatives. This is most evident in renovation projects, because within the business of new building, competing alternatives are in the same price range as this company's. In renovation, alternative solutions have up till now mainly consisted in construction on the site by workmen with diverse skills. The prefabricated solution has potential to be less costly than this alternative for several reasons: Because of the systematized and standardized production and preparation of elements at the factory, economic benefits of large-scale production are achieved. Moreover, prefabrication means that less man hours are spent on establishing each unit on the site. This represents a cost saving in itself, and it also reduces the risk of unplanned project cost escalations resulting from delays in one construction activity causing further delays in related activities. An additional explanation for the relative low cost of the company's solution is the potential reduction of the fee that building owners pay to third parties in construction projects: With the prefabricated solutions, engineering consultancies are content with smaller fees than when building parts are constructed traditionally on the site. Due to the high level of foregoing preparation and the resulting low number of workers and man hours on the site, there is less need for these third parties' control and coordination of construction and establishment activities than otherwise. Another important, economic incentive for choosing this system product concept is that it lessens the need for re-housing residents compared to traditional renovation solutions. When planning renovation of blocks of flats, residents may be reluctant to live with artisans coming and going in their homes for several weeks. Residents are therefore often re-housed at hotels or the like, which can be a considerable expenditure in itself. With this alternative renovation solution taking only 14 days to install, residents are logically expected to be more willing to accept the temporary inconvenience and may therefore not need re-housing. Being able to let residents stay in their own homes during the renovation period, the system product thus presents housing associations with an economic advantage and residents with practical comfort. These sources of potential economic benefits of prefabricated system products are perceived as important sales arguments, as expressed by one informant: "In the end, price is decisive for the building owner's choice of a product".

Reduction of complexity: As mentioned in the introductory outline of system products, a potential and advantageous outcome of such products is the reduction of complexity facing other actors in construction projects. This outcome seems highly desirable in the construction of this particular building part because its employment of several technologies and variously skilled workmen makes it a rather compound and often time-consuming part of construction projects. Our case company's concept does indeed confine some of the complexity facing building owners or their partners because the entire purchase is gathered in one package solution placed at one responsible supplier. This means that decision-makers only have to communicate with this supplier who has the general idea of what is possible and what effect specific wishes will have on the overall solution. It also means that only craftsmen from this supplier will work with the building part on the site. They work according to an installation process which is developed internally so building owners or their consultants do not have to spend resources planning and organizing the usual numerous artisans working on this building part. Moreover, compared to traditional approaches, our case company apparently has an ability to orchestrate cooperation among the conducting parts involved in the establishment: potential conflicts among the workers about, for instance, who is responsible for delays and who should be compensated for waiting time are, according to one informant, less of an issue when they are all employed by this same firm.

Consistent quality: Also this general point on system products describes the construction solution studied here. Indoor production under controlled conditions ensures a high, steady quality of the products because they are produced in accordance with well-tested, automated processes making the quality less dependable on the skills and experiences of individual artisans. Such consistent quality gives customers a positive assurance that the functionality of their products will not be compromised by inattentive craftsmen. The making in a factory also influences the fixing of purely visual aspects of the product; they can be carried out with greater perfection than by artisans on a production site. Ironically, the accuracy enabled through settled production processes makes little, appearance-wise irregularities stand more out visually than if all surfaces show traces of more labour-intensive preparation. To avoid such irregularities spoiling the overall impression, the consistent quality therefore imposes a very careful design of certain solutions with regards to assembling points of framework elements and between these and other elements.

Flexibility: Various types of flexibility are inherent in the product. Economically, the initial decomposition of the delivery in separate components enables the company to respond flexibly, should a need for retrenchment in individual projects arise. If demands for cuts in expenditure are introduced during a construction project, the company can offer savings within this delivery by e.g. replacing some of the chosen equipment with more low-priced alternatives. The decomposition of the delivery makes it relatively easy to create an overview over the obtainable savings through the exchange of specific components – the prices of the alternatives are simply entered in a price calculation sheet as substitution for the original ones and the savings are calculated. It follows implicitly from this description that the concept is also practically flexible since it enables such replacement of components. The scope of this flexibility is discussed at more length in following sections. Additionally, in renovation projects, the establishment activities associated with this solution are also adaptable due to the fact that it is lightweight solution. Heavy alternatives have to be either made on the site or else the buildings have to be opened up so they can be hoisted in. The case company’s solution, on the other hand, can be carried up by workpeople, and building owners do therefore not have to adapt and prepare their buildings as much for the renovation activities as otherwise.

Maintenance: A final pronounced rationale for choosing the outlined construction product is that it makes it easier to repair and replace damaged elements and sub-elements after the products have come into use. Elements and parts of them can be exchanged if they come to pieces or they can be temporarily removed without being damaged in the process which facilitates e.g. repair of behind lying or adjoining building parts. The structure of the product thus facilitates future maintenance and in this sense also presents customers with some flexibility in the long term.

It follows from this outline that the company's prefabrication strategy introduces a specific balance between standardization and customization which seeks to avoid the disadvantages of traditional custom-built construction while also avoiding the uncompromising character of pure standardization (Lampel & Mintzberg 1996). The first advanced benefit of modular architectures (cf. question 1), the ability to manage complexity, activities and resources, is the primary objective of so-called single-system modularization, which emphasizes decoupling of subsystems within specific, often one-of-a-kind projects in order to achieve rationalization effects (Miller 2001: 107-8, 188). The case company explicitly attempts to achieve this type of advantages with its system product, because the above-mentioned benefits deduced from our interviews can be summarized as a means of claiming responsibility for the overwhelming complexity of construction processes through prefabrication of functional solutions and doing this in a cost-saving manner. Moreover, the company's marketing materials as well as our interviewees emphasize a perception of all projects as unique resulting in a need for taking each case's characteristics into consideration in the design of products and installation processes: "To us, every project is really the beginning of a new prefabricated product where we reuse from preceding ones". The other mentioned theoretical rationale behind modular product architectures, rational creation of variety, emphasizes interchangeability and is referred to as multiple-system modularity (Miller 2001: 107). This is obviously also an intended object of this product strategy, because, as mentioned, the adherence to similar production and establishment processes enables the company to reuse its solutions in projects with diverging end results. By offering to deliver a range of some components in different colours and materials and other components in different designs and materials, the company addresses various customer preferences without compromising its standardized production processes. Ongoing product innovation is less of an explicit object with this system product, since the company does not itself develop the equipment to be integrated in the delivery and it adheres to the original construction of the framework elements.

The fact that offering substitution is not the dominant rationale behind this system product, but that managing complexity is also an important rationale, may seem peculiar, bearing in mind that much literature stresses substitutability as a distinct advantage of modular product architectures. However, one also needs to remember that modularity is often pointed out as an alternative to integral, preset packages offering customers no co-determination (Langlois & Robertson 1992: 79) or at least presenting far-reaching consequences of every desired change (Ulrich 1995: 426). This does not describe the traditional alternative to the case company's concept; rather, the long-established method for constructing this building part represents close to pure customization to the extent that '(…) the customer's wishes penetrate deeply into the design process itself (…)' (Lampel & Mintzberg 1996: 26). Against the background of this tradition, it is understandable that the possible variation is not emphasized as the ground-breaking aspect of the system product but instead stressed as a possibility together with the advantages of cost-efficiently managing complexity.

Addressing complications: Realization of the system product

This section presents the efforts and decisions that our case company makes to succeed with its system product and thereby illustrates factors which sometimes complicate this business. Collaborating with an international partner with well-established production facilities and making connections with sales agents abroad, this particular company was probably from the beginning less hindered by the small-volume Danish market than other firms devising system products for the Danish market from scratch (Mikkelsen et al. 2005: 32, 36). Despite this cooperation advantage and despite the product advantages outlined above, the dissemination of the system product in Denmark seems to be more than just a trivial matter. The case company has indeed managed to make several decision-makers aware of the benefits and choose the product for their construction projects, but it has so far secured less than the assessed market potential. And it has, since the product was launched, experienced various hurdles requiring managerial consideration in sale, design and establishment. These are presented below in a discussion of the empirical findings resulting from our enquiries into the aforesaid hypotheses.

A) Meeting diverse external needs

Modular product architectures can systematically meet individual customer demands through different configurations of interchangeable components resulting in several product variations (Baldwin & Clark 1997: 86; Garud & Kumaraswamy 1995: 47; Sanchez 2002B: 670; Victor & Boynton 1998: 166-68). The structure of the examined prefabricated building part does indeed enable the company to cater to diverse needs. For instance, buyers are free to decide for themselves which sizes, colours and materials they prefer for some of the equipment. The company is also willing to implement basically all available variants of certain functional equipment meaning that a buyer can configure his product of whichever models of the equipment he likes and which harmonize with the look in the rest of the building.

However, this modification of the products is not accomplished utterly through standardized configuration, since not all interfaces are kept constant. Some parts can indeed be reconfigured without much consideration due to the existence of common standards which the majority of sub-suppliers adheres to. Modification of other parts is brought about by a more individualized adaptation meaning that the case company adapts certain of its own processes and solutions to the needs of specific customers. For instance, some customers demand rather atypical details in this building part, in which cases the company often designs those things to order so that they fit in with the rest of the prefabricated product. Another, very apparent, adaptation to the respective projects is the arrangement of surface sub-elements. These are always adjusted to the chosen equipment as well as the varying geometric dimensions of the solution so as to ensure a harmonious visual appearance. This shows that not all types of interfaces are specified and standardized; particularly, 'spatial interfaces' – the spatial location and volume a component may occupy (Sanchez 2000: 613) – are not set but depend on the individual construction projects.

It follows that the company is able to cater to diverse product needs, and that the extent to which it does this merely through standardized configuration depends on both the existence of common standards in the components to be exchanged as well as internal assessments of the necessity of demonstrating more responsiveness to the characteristics of different building projects than would be possible with completely fixed interfaces.

B) Designing individual project solutions

When supplying firms adhere to standardized and set modular architectures, products are compound by '(…) "mixing and matching" a range of "plug-and-play" compatible components (…)' (Sanchez 2002A: 227). Although the case company's product concept enables it to meet tastes and needs of various customers through different configurations, the concept does not enable entirely straightforward creation of variety as implied in this quotation.

First, as indicated above, meticulous and detailed design of surface solutions is an important part of the planning phase in each project. The extensive planning work to make the chosen type of surface fit with the requested product dimensions and the chosen equipment in each project shows that the case company does not adhere to a minutely developed modular architecture and that some product variations thus require an effort. Spatial interfaces are not fixed since the management does not believe in a strategy of standardizing the entire solution – some customers order untypical equipment, some want traditional equipment but in various quantities, and to be able to meet these requests and still ensure a good-looking result, extensive planning of surface solutions is necessary in each project. In this projecting phase, the case company also needs to take into account the other parts of the building, meaning that the company does not perform ready configuration. As one informant put it: "(…) Obviously, the [product] you insert must fit with the other parts of the building. So you need to examine the other parts of the building, and you need to know where the points of connection to the other parts of the building are. So obviously, there are lots of flat projecting-wise matters you have to get acquainted with (…) And we spend a lot of time on that in each case to ensure that we make the right product to the customer".

Second, also the fact that the time of involvement in specific projects has considerable influence on the ease with which the company can utilize its concept shows that planning of projects is not merely a matter of mixing and matching. Ideally, one informant said, the company would like to receive a rough drawing of the geometric measures of the planned building parts and then be allowed to draw them and thereby help the architect give consideration to the system product solution. On several occasions, the company succeeds with this, but there are also numerous situations where it is not implicated until building projects reach their projecting phase and bids for the establishment of the building part are invited. This means that a sketch of the preferred solution has already been drawn, and having to tender for a contract on such terms can impede realization of the system product's benefits. For our case company, the perceived drawbacks of entering building projects this late include a reduced means of affecting the physical settings and the design and delimitation of the delivery in a direction which considers the concept's strengths and limitations. For instance, it is beneficial for the company to gain influence on the sizes of the various elements so that they are adjusted to its means of transportation since its carriage costs represent a rather large part of the products' final price. The company may, in cases where it does not gain early access to a specific project, have to come up with alternatives to the solutions originally devised requiring efforts to changing this first idea. Said one informant: "It may be that a traditional projecting has been made, and then it can be quite a task to suddenly replace it with something different. Then new drawings have to be made. So yes, there are clear advantages of being involved early". As a consequence of these difficulties, the informants have sometimes experienced that decision-makers in concrete construction projects appreciate the system product concept but maintain the solution originally planned and then hold out the prospect of involving the case company earlier on in future projects and thereby consider its product concept. The point that early involvement in projects is important to influence the choices of architects and others suggests that preserving focus on customers' somewhat unique needs while utilizing the potential for reuse in the system product concept, and doing this in changeable settings, is not a trivial matter.

Third, the varying ease with which mix and match configuration takes place depending on which component is to be replaced means not only that the preferences of different building owners are not effortlessly met as stated above, but also that it is complicated to individualize certain features of the products within projects. The case company considers certain things in its product "basic" once a design option has been made for a project, and it is therefore somewhat reluctant to let residents have multiple options in these elements within the same project. During the design process, particular consideration is given to implementing these things based on the specifications of the individual construction affair. For these things, component interfaces have thus not '(…) been specified to allow the "substitution" of a range of component variations into the architecture without having to change the designs of other functional components in the architectures' (Sanchez 2002B: 668). Therefore, once such solutions have been devised, their exchange with alternatives within the same order can be rather complicated and require a certain volume to justify the adaptation effort, which is not achieved if all residents choose unique variations: "We often meet a limit if customers want to leave all choices to the residents (…) If we do not have prospects of delivering two identical [products], we decline the case (…)".

Fourth, this reluctance towards individualizing single solutions within specific projects is also apparent in some elements which in fact practically allow the ready mixing and matching characterizing modular architectures: Even when variation of elements does not require compensating changes in the rest of the delivery, variety of elements internally in projects can present considerable logistical problems as well as control-wise costs. Particularly, the informants stressed that it is demanding to undertake and deliver orders with surface solutions in optional colours. If one unit within an order has to have surfaces in unique colours, the case company production-wise considers it another type of product. Multiple colours increase the risk of making mistakes in the production and of installing a specific product in the wrong place of a building and therefore require more control of these processes. This kind of individual configurations is therefore also considered more cost consuming and thus limited.

Altogether, this suggests that designing the prefabricated construction deliveries is not merely a question of prompt configuration. The practical features of the studied system product do thus not correspond entirely with theoretical accounts of modular systems characterized by standardized configurations of components which are all in accordance with carefully defined interface specifications. Instead of restricting its solutions to 'plug and play' compatible components, the company allows buyers to choose some product aspects from the market's offerings and then aims to integrate these with the concept. However, we still perceive the subject of our examination as representing product modularity. This is so because if one chooses to view the concept modularity as '(…) a continuum describing the degree to which a system's components can be separated and recombined (…)' (Schilling 2000: 172), theoretical descriptions such as the ones cited above probably describe the most sheer form of modularity in which configuration is only a minor consideration due to a high level of independence between components enabled by very high levels of detail in the standardized design rules. In this graded understanding of modularity, the possibility of combining the elements of the studied product may, despite its limitations, be said to situate it on the modular side of the delineated continuum as opposed to more integrated systems represented by preset packages which prevent customers from compiling individual products (Langlois & Robertson 1992: 79).

Resulting considerations

The informants' explaining of these delimitations in the ability to "plug and play" has suggested to us that certain managerial considerations seem to accompany the business of implementing this system product in construction projects. Since launch of the product, the company has learned – sometimes the hard way – about the product's practical capacities and limits. As employees in a new department, the informants have had to work hard to receive orders and sometimes, contracts have been considered so vital that attention has been paid primarily to complying with customers' wishes and not so much to the practical limitations of its concept. Through experience, the company has learned more about what it can and cannot implement in its product and that it is inexpedient to compromise on certain things to get an order. Try-out and subsequent assessment of different product adaptations has enabled more precise definitions and delimitations of the concept which facilitate overview over the wishes the company can fulfil without hindering attainment of the above-mentioned efficiency and standardization advantages. As a result, the company sometimes advises potential customers to have someone else build very special solutions in small numbers on the site rather than offering to make them as prefabricated solutions, if this latter approach is clearly not worthwhile.

Another managerial concern related to the recurrent need of planning rather than merely configuring each project is the recurrent need of weighing up the benefits of a good or potentially good customer with the drawbacks of accepting small batches within larger orders or just small orders. In external communication, the company stresses that its concept allows individualization, implying that it can meet divergent needs. However, one informant stated that for the company to deliver whatever customers request, it has to receive very large batches or else the solutions will have to be more equalized within projects. Basically, the smaller the project, the more things need to be equalized in order to ensure a certain batch size. Assessing how far to go, i.e. how much variety to offer within individual projects and how small batches to accept is, however, not only a matter of economic calculations. In some construction projects, contracts may, for instance, be for 100 similar deliveries plus a small number of different ones. The case company then sometimes decides to accept the expenses resulting from delivering the very small batch in order to ensure the large batch of 100 identical products. Likewise, it is sometimes deemed worth the while to accept very small projects of for instance eight units in order to cultivate good relations with a cooperation partner that may later order the preferable larger batches.

Additionally, limitations in the ability to simply mix and match components cause a perceived need of so to speak “instructing” customers and cooperation partners to make them understand that there can be a price to pay for the advantages of this system delivery. That price can, for instance, be limited opportunity of all residents to have their solution completely customized – they may initially decide on the measures of the solution while the case company decides what scope for variation it is prepared to offer given the sizes of the batches in the order. Another consequence associated with implementing the system product is that this supplier sometimes tries to reduce architects’ opportunity of completely utilizing the space available for each solution. One rationale for doing this is that if the physical spaces available for the product differ within the same order, it can be more beneficial for the case company not to utilize the largest of these spaces and thereby bring about some larger batches of equal products. Another reason for attempting to define the measurements of the products ordered in a project can be to make allowances for internal transportation from production to building site so that this transportation is not made difficult due to awkward sizes of elements. As compensation, customers are then sometimes given the assurance that they will get the best price or a free hand to decide the equipment if they accept these specific measurements.

In order to ensure the consideration of these issues related to the system product, the company seeks influence on their customers’ choices, partly by gaining early access to projects and partly by cooperating with architects and engineers of building projects so that these parties can help customers plan for the constraints of the system product.

C) Product establishment

‘Product modularization implies a product design approach in which a product is assembled from a set of independent modules’ with standardized interfaces (Lau & Yam 2005: 434). This suggests that the assembling activities associated with modular products are not particularly demanding. Since we have already established that our case company does not adhere exclusively to accurately defined interfaces due to the changeable settings for its construction delivery, it is relevant to find out if the establishment, in similarity with the planning of projects, is somewhat subjected to the idiosyncratic details of individual projects or if realization of projects passes off as simple assembly of standardized components. The company has developed a basic procedure for how the products should be assembled and installed in renovation projects. This is a rather simplified instruction which only describes assembly of the plainest solution. In cases where the company consents to deliver solutions with more rare or unique product details, this basic procedure is not sufficient. Instead, assembly and installation rest on the ability of the employees on the site to identify and carry into effect the appropriate initiatives given the specificities of the case.

From our informants' description of the company's planning of and experiences with on-the-site activities, it moreover appears that establishment of the system products is affected by several aspects of the changing settings in which they are implemented. In renovation, there may be logistical and access-related features which complicate the establishment activities. Physical means of access are always examined before any contract on delivery is made, since potential hindrances in and around a building can make time schedules and budgets slip if they are not taken into account at the outset. It may, for instance, be necessary to prepare the surroundings for the arrival of the system products and to obtain relevant permissions. The conditions inside a building can also complicate the transportation of the system products to their final destination and thus make it more time and cost consuming. These experiences have taught the company that it can facilitate establishment activities by examining the physical settings before arrival on the site and that the establishment activities form a considerable part of the cost in itself which needs to be taken into consideration when submitting offers to ensure realistic budgets.

Also the different humans who our case company works for and together with influence the way establishment of the system products proceeds. Although the system product delivery encapsulates several processes, this supplier is still part of larger construction projects with mutually dependent actors. During a renovation project, the company is thus dependent on external craftsmen, since some of their activities have to precede the establishment of the system product. Similarly, external parties working on the site are sometimes dependent on our case company to complete its establishment activities, because until then, they cannot initialize their own activities. The case company therefore negotiates with external parties on the details of time schedules so as to optimize the construction process. The impact of external actors on the establishment of the system product is also reflected by the resources the case company uses to decide upon unforeseen issues which apparently always emerge on an ongoing basis during establishment: When the case company's workmen carry out establishment activities on a construction site, they are in daily contact with the project manager to talk over various details and questions of doubt. Moreover, the case company also experiences a need to pay attention to other actors' behaviour to make sure that they do not, due to lacking consideration, damage the system product during their own construction process. This has happened on several occasions, with following additional costs, delays and resources spent on allocating the responsibility. These dependencies and adaptations indicate that also suppliers of system products are subjected to the interdependencies and incomplete planning of construction projects. In the words of one informant, "[i]n construction, you have a plan till you make a new one".

D) Product development

When precise, unambiguous and complete design rules of a modular system are laid down, developers can design new components independently and in parallel – they do not need to take into consideration the outcome of other development efforts but can simply be guided by the product architecture's design rules (Baldwin & Clark 1997: 84-86; Lau & Yam 2005: 433; Sanchez & Mahoney 1996: 66; Ulrich 1995: 435). We have already established that the system product in question does not embody textbook modularity, and this seems to also show impact on the development of new product variations: Not all introductions of alternative and innovative product components are developed and implemented as frictionless with this concept as described in modularity literature. The main divergence seems to consist in the fact that our case company has not initially laid down a definitive modular structure with standardized component interfaces and subsequently outsourced delivery of components. Rather, it attempts to compile solutions based on the standardized framework elements and available, externally developed components, which are not necessarily devised with this product structure in mind or guided by its design rules. Indeed, independent product development in accordance with the architecture does take place when external development of alternative components observe existing standards and the components therefore relatively easily can be inserted in the system product. This is the case of some components. For others, it is not certain that new models follow the same standards as existing ones and implementation is therefore more complicated as described later.

Further development of the internally produced framework elements is also not exclusively a question of decoupled processes by means of which new components are devised in keeping with the product architecture. Adaptation of these elements' sizes and dimensions is almost effortless as explained, but product development seems to require more joint consideration. For instance, the company prefers to maintain variants of its current surface solution rather than to pursue other types of surfaces which may in fact be easier to integrate in individual projects. The reason is that they would disrupt the production processes and thereby complicate the handling of the entire delivery more than the current solution. On one occasion, the company accepted to change part of the surface to another type because an important customer requested it. This development effort was organized as a collaboration between the facility producing the system product and an external producer of the alternative material who jointly decided how this product development could be implemented in the system product. In addition to production considerations, the complex regulations of construction deliveries also hamper independent development of sub-components. The case company has obtained an impartial authorization of the functionality of its system product. If basic things in the primary structure are changed, there is a risk that the functionality of the products will no longer be guaranteed by this external party or at least that resources will have to be spent on obtaining further authorizations. Product development of such basic elements therefore cause additional concerns of the renewal of authorizations and anxiety for injuring the company's reputation in case new initiatives are not authorized or do not function as well in practice as the current one. These considerations indicate that in construction, not only concerns for internal operations influence decisions about component development but also the pronounced focus on regulations has a say.

This outlined departure from the decoupled development processes of modularity in theory does not seem to be a direct outcome of the fact that buildings are varying but more from the fact that our case company has defined and received authorization of a product architecture which only applies to the use of certain basic things. In order to establish whether there are more direct connections between inconstant physical settings and the ability to let independent designers be guided by design rules, the issue should probably be examined in a case company which pursues modularity more categorically, i.e. one that initially identifies an unambiguous and complete modular architecture which all developers observe.

E) Responding to changing trends

The considerable focus on buildings' appearances and the shifting trends within several building parts support the case for modularity since it has the potential to facilitate the meeting of such changing trends: 'Modular product architectures can be an important source of strategic flexibility (…) when they enable a firm to respond more readily to changing markets and technologies (…)' (Sanchez & Mahoney 1996: 66). To address the final stated hypothesis, this section discusses whether or not the examined system product, with its constrained modularity, enables the case com pany to respond flexibly to changing customer preferences. We have already established that for some relevant equipment, common industrial standards make the catering to specific customers possible without changing other elements. We will therefore focus on one example of the opposite, which was brought up by several informants during interviews.

Among the numerous pieces of equipment implemented in this product is a vital, functional part. The company has used the same version of this part in all its projects, and the rest of the product therefore complies with this part. Recently, an alternative piece of equipment performing the same function has emerged on the market. This solution, which is fundamentally different from the traditional part used by our case company, is visually appealing and apparently becoming increasingly more popular on the market. In one project, the case company agreed to deliver a batch of products with this solution on the request of a customer. As the employees did not have experience with it, they did not know beforehand how it would affect the production to implement such a solution. The experiences showed that this divergent part clashes with the rest of the product structure and that with this part, the solution is noticeably different from the one which has been externally authorized. It is therefore both more difficult and more risky to deliver this solution, and the informants are very reluctant to offer products containing this alternative part again. The company can thus not readily respond to this particular trend as it can with other, more standardized, elements.

This example reflects a common theme in modularity theory, namely the necessity of making a distinction between exploitation of current architectures and exploration of new ones, which is necessary since all technical architectures have performance limits (Chesbrough 2003: 175). Contemplating the organizational future position to the new, not compatible type of equipment in a sense means making a decision upon this exploitation / exploration issue: Should the company maintain its product structure with the current piece of equipment which is authorized and with which it has good experience? Or should it look more into the possibilities of developing the product concept further in order to be able to embrace emerging product innovations and perhaps even attempt to lead the further development itself? Certain considerations favour the latter approach, including potential enhancement of the ability to compete on the long term (March 1991; Prencipe 2003) and the possibility of earning first-mover advantages (Lieberman & Montgomery 1988). However, the internal attachment of importance to the documentation of the products' functionality stemming from the external authorization, combined with the fact that considerable effort and uncertainty are associated with further development of the product concept, supports the case for exploiting the current product. One informant mentioned that he prefers the company to hold on to the current solution to the extent practicable, i.e. until the preferences of trendsetters catch on in the market and the company has to adapt. Taking a stand on the extent of one's confidence in a product's future value on the market and paying attention to developing market trends thus seem to accompany the business of supplying system products.

Further insight

The description of our enquiries into the outlined modularity hypotheses has suggested that the physically shifting settings for this system product and the resulting different requirements to the system product hamper the case company's ability to meet diverging needs through utter configuration of standardized components. Additionally, other types of complications associated with the supply and implementation of the system product not covered by our hypotheses have emerged from our data collection. These will next be delineated.

If our sub-question A) concerning whether or not the system product enables the company to cater to diverse needs is broadened to include not only end users' needs after handover but also the needs and preferences of cooperation partners and decision-makers during the construction process, the answer seems to be more nuanced. There are apparently also other needs at stake during construction than those described under "rationales" which are not directly met through the system product. This is evident from our informants' describing of a certain reluctance towards prefabricated products as opposed to traditionally constructed solutions which they have experienced among different actors. In one construction case, the contractor who was hired was unhappy that our case company was assigned the work with this particular sub-system, since the scope of his own assignment was then smaller than if he had had responsibility for the entire case himself. This conflict of interests had rather negative impacts on the cooperation during the project. They also reported an impression of unwillingness reflected in, for instance, some engineers and architects speaking in favour of traditional solutions as well as some building owners choosing competing solutions for their projects even when these seemed to be clearly more expensive than the case company's offered solution. This shows that price is not always the paramount basis for decisions in construction and can reflect at least two things: That actors are tradition-bound and unwilling to try something different from what they are used to and / or that the system product, in addition to its benefits, presents shortcomings not experienced at traditional construction. The first of these interpretations may provide some explanation, since the supply of the system product does indeed influence the business of other actors: Architects and engineers face a need to compromise on their common practices to meet the system product, and some contractors' usual efforts are made unnecessary because our case company prefers to deliver directly to building owners and thereby avoid price increasing intermediaries. Some external actors therefore have to cede competences and fees when this system product is chosen, and it is thus possible that they consider it in contrast with their individual interests and therefore are sceptical of the product.

There seems, however, also to be reason to investigate the second type of explanation for some actors' reservations about system products. We mentioned earlier that in similarity with general statements on system products, the examined product concept reduces complexity since this supplier takes responsibility for an entire package solution and reduces the number of companies as well as workmen participating in construction projects. But there are also indications that the system product in other ways introduces additional considerations to take into account, which are partly reflected in the fact that it is important to the case company to enter specific projects early: First, the aforesaid attempt to standardize sizes and shaping of the products within projects in order to consider the efficiency of production and installation indicates that the system product necessitates decision-makers' consideration of the concept's establishment activities when they decide on the appearance of this particular part of their buildings. Second, the high transportation costs and the case company's resulting occasional attempts to adjust specific solutions to its means of transport similarly points to an additional factor to be considered when deciding on the details of the solution. The system product concept thus reduces some complexity in construction projects, but it also implies that certain things need to be considered during the planning of general building projects in order to obtain its potential for lowering costs.

We moreover stated earlier that system products offer a certain design flexibility by enabling products to be configured based on customers' preferences and components to be replaced with alternative ones. This point as well seems to be ambiguous since the system product also in a way reduces flexibility: Rather than taking customers' or architects' expressed design preferences as its point of departure and then making each solution accordingly, the case company has defined some set features and offers some elements in constrained numbers of alternatives. Particularly, the informants' mentioning of difficulties in working with architects, who give emphasis to aesthetic concerns and cultivate diverse particulars, indicate that there is a certain trade-off between aesthetic and standardized solutions or at least that combining the two concerns requires intentional efforts. The informants pointed out that aesthetics and price-consciousness are sometimes, in the Danish construction industry, weighed in a manner which considers the interests of architects while impeding the production of standardized solutions. They stressed that to realize the potential inexpensiveness of the system product, the producing company needs to have a considerable influence and thereby have a possibility of restricting the solutions to some standardized, modified products rather than completely tailor-made solutions.

Translating modularity into practice in construction

The case company is inspired by the principles behind modular products such as computers and by the idea that customers can configure their own products based on different available components. But it has modified the idea somewhat and adapted it to some pragmatic considerations experienced in the concrete construction context. This suggests to us that the circumstances are basically different in Danish construction than in industries which have enabled textbook modularity and that these dissimilar circumstances hinder a direct appliance of their version of modularity to the construction context. Particularly, the findings of this single-case study motivate the following hypotheses concerning what complicates textbook modularity of construction sub-systems and which modifications of the modularity principles this may result in:

- *Customers and cooperation partners in construction are used to considerably more customization than their counterparts in industries of traditionally mass produced products.*
  For some industrial products, the alternative to modular products consists in inflexible preset solutions. In opposition to this, actors involved in construction projects, such as architects, are used to be free to decide the materials of the different building parts and to define the degree of variety within projects. The limited scope of variety inherent in system products is therefore not expected to raise as much enthusiasm as for instance the possibility of configuring one's own car in opposition to choosing a preset one.

- *The varying characteristics of buildings complicate the maintenance of highly specified modular architectures in system products.*
  Within the field of some modular appliances, the electrical installations required to take the systems into use is present in most buyers' homes or offices, which simplifies delivery. The system product, in opposition, needs to be installed in unstable surroundings and thus forms more unique dependencies with the individual settings in which it is implemented. The employees in our case company therefore face a need to always get acquainted with the features of the individual construction projects, such as where specific, adjoining building parts are physically placed, and then to adapt the design of the system product to these.

- *In the attempt to observe the high demand for custom-making as well as the modularity principle of configuring products, companies may end up offering 'pick and choose' opportunities rather than 'plug and play'.*

The resources spent on making specific, sometimes unfamiliar, components fit with the rest of the system product as desired by customers show that our case company does not restrict its offerings to predetermined varieties enabling easy plug and play. Rather, in the attempt to meet customers' diverging needs, it seeks to implement the components they have identified and prefer among the market's offerings – an approach we can call "pick and choose". This implies spending more resources on the configuration of individual solutions than if a detailed product architecture were defined and retained. Spending these resources and thereby observing customers' demands is not necessarily unsuitable, considering that the company faces customers and cooperation partners with particular design-wise preferences and that the products form interdependencies with the varying surrounding buildings. But such an approach is likely to water down some of the theoretical advantages of modularity.

- *Suppliers of system products participate in organizations of numerous actors who are not necessarily interested in adjusting to the preferences of these suppliers.*
  Many construction projects involve a buyer – the building owner – who is not the end user as well as a number of professional opinion-forming actors such as architects and engineering consultancies. It is therefore not sufficient to define a system product which considers the end users' needs for configuration – suppliers may also have to pay attention to the needs and preferences of other participating actors as these can be decisive for the placement of orders. These actors have developed a prevalent procedure of involving subcontractors for this building part *after* design preferences have been identified which does not take into account utilization of the system product. In order to deal with the pronounced need for entering construction projects earlier than traditionally, suppliers of system products have at least two opportunities:
    - Facilitate replacement of the current common organization of construction projects with a practice that involves subcontractors and suppliers in projects earlier and considers their product concepts when making design decisions.
    - Develop tools, e.g. configuration systems, which make decision makers in construction capable of considering the respective system products' possibilities and limitations earlier in their processes and make their decisions accordingly.

  The first alternative will probably be quite a challenge for individual companies and may require a certain bargaining power vis-à-vis those actors who do not have a direct interest in this change, as well as a long time frame. The second alternative will probably require that suppliers enlarge their competences by developing skills within technologies different from their current core competences. It will also require that suppliers define the interfaces and limits of their systems explicitly to provide decision makers with an overview over the configuration opportunities.

Conclusion

This study has argued that a need to reduce complexity in construction projects supports the case for system products. They can reduce complexity on construction sites as well as during planning by diffusing responsibility for construction details away from central planners. Moreover, desires of bringing about faster, less costly solutions and reducing the dependence of construction projects' progress on weather conditions and individuals working on the site are met with system products. The study has also suggested that other factors in the construction industry complicate the spread of system products, including the traditional organization of construction projects, the reluctance of certain external actors to embracing the divergent features and demands of system product supplies as well as the design limitations inherent in the concept. Implementation of the products is moreover complicated by a perceived recurring need to adapt the design and establishment process to the characteristics of individual construction projects. Many of the findings reported on the preceding pages concern a weighing out of the benefits and shortcomings of pursuing either textbook modularity or allowing more individual customization in system products. These are here summarized as a discussion of pursuing 'plug and play' versus significant adaptation to single projects.

Adhering to unambiguously defined modular architectures in building parts and abstaining from altering them in individual construction projects enable cost-effective, systematic achievement of variety. Due to the up-front descriptions of components and their interfaces, only few resources have to be spent on making each solution. This gives suppliers an opportunity for offering cooperation partners faster delivery and for presenting end-users with more design options *within* individual projects, because when each solution does not have to be devised through human-intensive design processes but can be easily configured, the need of large batches will logically be less pronounced. Loyalty to set specifications of a system's elements can moreover have the advantage that even newly employed, inexperienced workmen will be able to assemble all variants of the system product based on a basic description of the procedure, since all components have the same interfaces and all assemblies will thus be similar. This implies that workers' familiarity with particular solutions will be a rather unimportant issue. This approach is, however, also associated with design limitations in terms of not offering atypical details breaking with the preset product architecture meaning that suppliers do not offer customization beyond certain limits. Such an approach can also prove inflexible when it comes to making the system product fit with the surrounding buildings: If suppliers are unwilling to adapt their own concepts, they may find it difficult to convince cooperation partners with other considerations to choose their system product, because then, the suppliers are in essence demanding that the surrounding buildings are adapted to their concept while showing no flexibility in that respect themselves. This hindrance is probably even more pronounced when suppliers are involved lately in a construction process where it is too late to alter the building design.

If suppliers of building parts instead relax the principles of modularity and adopt a more customization approach, they can avoid certain of the aforesaid shortcomings. By opening the way for product development at the architectural level rather than just at component levels, they can offer product variety that goes beyond what was imagined valuable when defining the system product architecture, which logically increases their opportunity of meeting customers' and decision-makers' actual needs. Such an approach also lessens the need for restricting architects' and engineers' opportunities when deciding how the product is to fit the rest of the building, and there is therefore a chance that such actors will support the solution. However, the design variety achievable with this approach is less cost-effective because considerable time and effort is spent on each solution and reuse of prior solutions is less pronounced. Moreover, the willingness to experiment with implementation of whatever component customers demand in the product system is costly when it turns out that some components do not fit appropriately with the other components in the system. In such instances, suppliers also risk that cooperation partners perceive them as unprofessional and therefore refrain from doing business with them in future projects.

Further research

This study has raised some issues and identified some managerial challenges related to the supply of system products. Given our focus on only one case company and our inclusion of only informants *within* this company, more studies are necessary to refine our understanding of the phenomenon further. These can beneficially attempt to assess the prevalence of the identified challenges, to seek confirmation or disproof of the suggested explanations for them and to discover further causal connections. Such studies should probably endeavour to recognize which actors have a real impact on the decision to use or not use system products and identify what their core interests are when participating in construction projects. Moreover, by following some decision-makers' process of contemplating using a system product in a construction project, future studies could hopefully define more specifically at which points system products contrast with these actors' preferences and how suppliers cope with those situations. Finally, this study has left us with an uncertainty about the significance of price when choosing building parts. The case company has experienced to miss orders to less expensive alternatives, but it has also experienced missing an order to a competitor with a more expensive alternative despite some decision-makers' declared satisfaction with its suggested solution. It would therefore be relevant for future research, in its attempt to clarify the interests of decision-makers as described above, to include an explicit focus on economic rationality and its potential conflict with other rationales.

References

AEGIS (1999): ‘Innovation Indicators in Building and Construction’, Prepared by The Australian Expert Group in Industry Studies (AEGIS), University of Western Sydney Macarthur

Baldwin, Carliss Y. & Kim B. Clark (1997): ‘Managing in an Age of Modularity’, Harvard Business Review, September-October, pp. 84-93

Baldwin, Carliss Y. & Kim B. Clark (2000): ‘Design Rules Volume 1. The Power of Modularity’, The MIT Press

Beim, Anne (2005): Forord, ’CINARK sætter fokus: Industrialiseret arkitektur. Økonomi – proces – produkt/værk’, http://www.cinark.dk/media/105.pdf

Brusoni, Stefano & Andrea Prencipe (2001): ‘Unpacking the Black Box of Modularity: Technologies, Products and Organizations’, Industrial and Corporate Change, Volume 10, Number 1, pp. 179-205

By- og Boligministeriet (2001A): ‘Tæt samarbejde i byggedelen – et bedre byggemarked’, Debathæfte 2, Projekt Hus, www.ebst.dk/file/1163/debathaefte_2

By- og Boligministeriet (2001B): ’Ny industrialisering – et bedre produktmarked’, Debathæfte 3, Projekt Hus, www.ebst.dk/file/1164/debathaefte_3

By og Byg, Statens Byggeforskningsinstitut (2003): ‘Nye generationer af byggekomponenter – Prisopgave for studerende ved arkitekt- og designuddannelserne’, http://www.sbi.dk/content.aspx?itemguid={0243C671-4B74-43CD-95BB-23B2077D96C3}&catguid={BBAA6F9F-4DBF-46ED-8520-63B6ECC069E8}

Chen, Kuo-Min & Ren-Jye Liu (2005): ‘Interface strategies in modular product innovation’, Technovation 25, pp. 771-782, www.sciencedirect.com

Chesbrough, Henry (2003): ‘Towards a Dynamics of Modularity: A Cyclical Model of Technical Advance’ in Andrea Prencipe, Andrew Davies, Mike Hobday (Editors) ‘The Business of Systems Integration’, Oxford University Press

Erhvervs- og Byggestyrelsen (2006): ‘Vision 2020 – Byggeri med mening’, http://www.ebst.dk/file/3878/vision2020.pdf

Galvin, Peter & André Morkel (2001): ‘The Effect of Product Modularity on Industry Structure: The Case of the World Bicycle Industry’, Industry and Innovation, Volume 8, Number 1, April, pp. 31-47

Garud, Raghu & Arun Kumaraswamy (1995): ‘Technological and Organizational Designs for Realizing Economies of Substitution’, chapter 2 in Raghu Garud, Arun Kumaraswamy & Richard N. Langlois (Editors) (2003): ‘Managing in the Modular Age’, Blackwell Publishing. Also issued in Strategic Management Journal, Volume 16 (1995), Special Issue: Technological Transformation and the New Competitive Landscape, pp. 93-109

Lampel, Joseph & Henry Mintzberg (1996): ‘Customizing Customization’, Sloan Management Review, Fall, pp. 21-30

Langlois, Richard N. & Paul L. Robertson (1992): ‘Networks and Innovation in a Modular System: Lessons from the Microcomputer and Stereo Component Industries’, chapter 3 in Raghu Garud, Arun Kumaraswamy & Richard N. Langlois (Editors) (2003): ‘Managing in the Modular Age’, Blacwell Publishing. Also issued in Research Policy, 21 (1992), pp. 297-313

Lau, A.K.W. & R.C.M. Yam (2005): ‘A case study of product modularization on supply chain design and coordination in Hong Kong and China’, Journal of Manufacturing Technology Management, Volume 16, Number 4, pp. 432-446

Lieberman, Marvin B. & David B. Montgomery (1988): ‘First-Mover Advantages’, Strategic Management Journal, Volume 9, Special Issue: Strategy Content Research, pp. 41-58

Lund, Lene Dammand (2005): ’Det bedste af to verdener’ in ’CINARK sætter fokus: Industrialiseret arkitektur. Økonomi – proces – produkt/værk’, http://www.cinark.dk/media/105.pdf

March, James G. (1991): ’Exploration and Exploitation in Organizational Learning’, Organization Science, Volume 2, Number 1, pp. 71-87

Mikkelsen, Hans, Anne Beim, Lars Hvam & Martin Tølle (2005): ‘Systemleverancer i byggeriet – en udredning til arbejdsbrug’, Institut for Produktion og Ledelse, DTU, http://www.produktmodeller.dk/nyheder/2005/Systemleverancer_i_Byggeriet.pdf

Miller, Thomas Dedenroth (2001), PhD Thesis: ‘Modular Engineering – An approach to structuring business with coherent modular architectures of artifacts, activities, and knowledge’, Department of Mechanical Engineering, Technical University of Denmark

Pine II, B. Joseph, Don Peppers & Martha Rogers (1995): ‘Do You Want to Keep Your Customers Forever?’, Harvard Business Review, March-April, pp. 103-114

Prencipe, Andrea (2003): ‘Corporate Strategy and Systems Integration Capabilities – Managing Networks in Complex Systems Industries’, in Andrea Prencipe, Andrew Davies & Michael Hobday (Editors) ‘The Business of Systems Integration’, Oxford University Press

Sanchez, R. (2000): ‘Modular architectures, knowledge assets and organizational learning: new management processes for product creation’, Int. J. Technology Management, Volume 19, Number 6, pp. 610-629

Sanchez, Ron (2001): ‘Product, Process, and Knowledge Architectures in Organizational Competence’, in Ron Sanchez (Editor) ‘Knowledge Management and Organizational Competence’, Oxford University Press

Sanchez, Ron (2002A): ‘Modular Product and Process Architectures: Frameworks for Strategic Organizational Learning’ in Chun Wei Choo & Nick Bontis (Editors) ‘The Strategic Management of Intellectual Capital and Organizational Knowledge’, Oxford University Press

Sanchez, Ron (2002B): 'Industry Standards, Modular Architectures, and Common Components: Strategic Incentives for Technological Cooperation', in Farok Contractor & Peter Lorange (Editors) 'Cooperative Strategies and Alliances', Oxford: Elsevier Science

Sanchez, Ron (2004): 'Creating Modular Platforms for Strategic Flexibility', Design Management Review, Winter 2004, 15, 1, pp. 58-67

Sanchez, Ron & Joseph T. Mahoney (1996): 'Modularity, Flexibility, and Knowledge Management in Product and Organization Design', Strategic Management Journal, Vol. 17 (Winter Special Issue), pp. 63-76

Schilling, Melissa A. (2000): 'Toward a General Modular Systems Theory and its Application to Interfirm Product Modularity', chapter 6 in Raghu Garud, Arun Kumaraswamy & Richard N. Langlois (Editors) (2003): 'Managing in the Modular Age', Blackwell Publishing. Also issued in Academy of Management Review, 25:2 (2000), pp. 312-334

Staudenmayer, Nancy, Mary Tripsas & Christopher L. Tucci (2005): 'Interfirm Modularity and Its Implications for Product Development', Journal of Product Innovation Management, Volume 22, Number 4, July, pp. 303-321

Thomassen, Mikkel Andreas (2005): 'Struktur giver frihed' in 'CINARK sætter fokus: Industrialiseret arkitektur. Økonomi – proces – produkt/værk', http://www.cinark.dk/media/105.pdf

Thorsen, Peter (2005): 'Gentagelse er en udfordring' in 'CINARK sætter fokus: Industrialiseret arkitektur. Økonomi – proces – produkt/værk', http://www.cinark.dk/media/105.pdf

Tushman, Michael L. & Johann Peter Murmann (1998): 'Dominant Designs, Technology Cycles, and Organizational Outcomes', chapter 10 in Raghu Garud, Arun Kumaraswamy & Richard N. Langlois (Editors) (2003): 'Managing in the Modular Age', Blackwell Publishing. Also issued in Research in Organizational Behavior, Volume 20, 1998, pp. 231-266

Ulrich, Karl (1995): 'The role of product architecture in the manufacturing firm', Research Policy 24, pp. 419-440

Victor, Bart & Andrew C. Boynton (1998): 'Invented Here: Maximizing Your Organization's Internal Growth and Profitability', Harvard Business School Press

Woudhuysen, James & Ian Abley (2004): 'Why is construction so backward?', Wiley-Academy, John Wiley & Sons Ltd

Yin, Robert K. (2003): 'Case Study Research: Design and Methods', Third Edition, Applied Social Research Methods Series Volume 5, SAGE Publications