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Modularization in the Construction Industry Using a Top-Down Approach

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Abstract: Throughout the last centuries, the manufacturing industry has experienced great improvements in efficiency and cost reductions, but the same improvements have not taken place in the construction industry. Based on the principles of mass customization that are known from the manufacturing industry, a case study of one of the largest construction companies in Northern Europe was carried out according to the principles of action research. This approach was used to clarify whether potential exists for using the principles of mass customization to improve efficiency and minimize costs connected with the construction of buildings; and if so, what they are. The main technical solutions used for residential and office buildings were analyzed using a top-down approach. These solutions were identified and their relations mapped using a Product Variant Master (PVM). When a satisfactory overview was achieved of the major technical solutions, a configuration system was made. Such a system is often used to communicate findings from the PVM to the user. Through the work of constructing the PVM and the configuration system, it was found that a great potential exists for implementation. Based on the findings and experiences gathered throughout the process, the conclusion is that the principles of mass customization are best used in the construction industry if used with a top-down perspective.

Keywords: Conceptual modules, configuration, construction, modularization, top-down modularization, product variant master, stepwise implementation.

INTRODUCTION

A major challenge for companies offering highly complex systems and highly engineered customized products is to reduce delivery times while increasing productivity and the quality of the finished product. To overcome this challenge, some companies in the manufacturing industry have developed and implemented principles from mass customization [1]. The solution to the challenge for the construction industry can be industrialized construction, which in this context means transforming traditional craftsmanship production to machine-based production [2]. Such industrialization can benefit from the principles of mass customization by allowing individual housing through standardized production; thus keeping costs down while increasing quality. This has been achieved in the production of cement factories by F.L. Smidth (FLS) in a sector similar to the construction industry. FLS successfully developed mass customization methods on the basis of experience gained working with modules and configuration systems. Can these methods and experiences be transferred to the construction industry?

Traditional modularization is done on relatively small objects that are produced and sold in great numbers, but modularization in the construction industry differs from this in many ways. In the construction industry, size and complexity demand untraditional modularization. In addition to the differences in size and amount of the objects produced, subjective demands also differ due to the individual customer's demands. The size of the market also differs from the traditionally modularized product market, since construction markets are fairly local. Construction companies operate in limited geographical areas, most often national or regional, where a certain construction style or tradition prevails.

When trying to understand a complex system, two different approaches are normally used [3]. Through the first approach, the top-down approach, the whole system is first divided into a few main components. These components are then divided into smaller components, and so on until a satisfactory understanding is gained. This is done on a conceptual level, which means that all the different components are not described in detail – only the larger parts. For example, in using a top-down approach for constructing a car, the focus would be on the chassis, the engine, the wheels etc., and without going into too much detail, these larger parts of the car are described. The second approach, the bottom-up approach, first examines the smallest parts and components and then combines them into larger components or parts of the product until a satisfactory understanding is achieved. An example of this could be a detailed description of the locking mechanisms in a car door. The different components and their functions would be described in detail. Then, they would be combined into the lock, then the door and so on.

When examining a complex field such as the construction industry, it becomes an exhausting task to look at every single detail, as in the bottom-up approach (see the lower part of Fig. **1**). Buildings are large, complex structures, which are produced in much smaller quantities than is normally the case in the manufacturing industry. A building's design is a compromise between many different stakeholders and their views on many different questions. Thus, there are endless numbers of possible combinations, which are often chosen on the basis of personal taste and subjectivity. This makes generalization difficult. The more general technical

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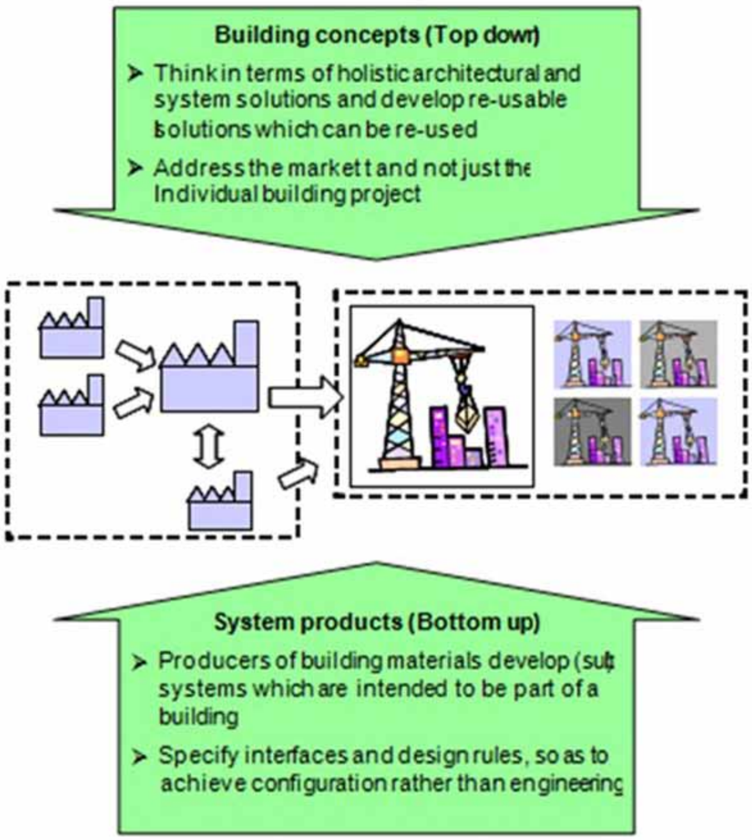

Fig. (1). Top-down vs. bottom-up approach [3].

solutions for a building, however, can be looked upon quantitatively and made configurable in order to reap some of the benefits inherent in the principles of mass customization [4, 5]. An analysis has been made of the implementation of mass customization principles in the construction industry in one of Northern Europe's largest construction companies, NCC Construction.

NCC, or Nordic Construction Company, is a Swedish construction company with activities in all of Scandinavia as well as the Baltic countries, northern Germany, Russia and Poland. In 2010, NCC had a turnover of SEK 49 billion (USD 7.2 billion). NCC has a tradition for seeking regional mass customization potential and has carried out such projects in Sweden, Denmark [6] and in Germany [7]. In Sweden, the regional department of NCC carried out a project to construct pre-fabricated house elements ready to be assembled after being shipped to the construction site. In northern Germany, NCC constructed a platform for the construction of low-cost residential housing [7]. These low-cost houses were constructed through the use of platforms that were connected to specific criteria. They were to be applicable for 90 percent of the selected market, be designed with respect for German architectural tradition, be flexible enough to produce many different houses, and use a decentralized serial production to enable construction of small projects. These smaller projects were viewed to be beneficial for embracing a greater number of building types in order to satisfy Denmark's smaller market.

Implementation of mass customization principles can be introduced in several ways. One way is a total implementation, where every step of the process or product is analyzed, and on this basis, the whole process is changed. Another way is gradual implementation, where parts or sub-parts are separated from the whole process or product and analyzed. Then, the process related to these parts is changed according to the principles of mass customization while still fitting together with the rest of the original process or product. The latter method involves a more conceptual approach, since its focus is just on the larger modules and does not include a complete implementation of the entire product. Dividing the construction into smaller parts to be modularized can also be accomplished on several levels – e.g. the component or unit level. As an example of the component level, we often see façade elements delivered today as finished customized sandwich elements comprising everything from façade cladding to insulation and fittings. Whole units can be customized and delivered ready for installation, as seen in the shaft case or in some bathroom solutions, where the whole bathroom is designed off-site and delivered ready for installation at the site.

In a case study in the construction industry, the hypothesis (see the hypothesis section), based mainly on experience from FLS [8], was tested. This is described in the methods section. The test was conducted as a research project at the Technical University of Denmark (DTU) in collaboration with NCC, one of the largest construction companies in Northern Europe. Throughout the project, the principles of mass customization have been applied to office and residential housing, since these types of buildings are most common.

THEORY

A Product Variant Master (PVM) was used in order to analyze the case company and its product range. A PVM is a tool in which a list of the products the company carries in its product range can be written along with their components [9]. For example, a bicycle company can use their PVM to show that they produce three different bikes. These bikes are then broken down into their components: e.g. wheels, saddle, gearing system, pedals etc. Using a PVM to analyze a construction project's main system allows the user to map the elements and the relations between different systems using different views. While these relations are being mapped, such aspects as constraints and relational behaviour can be added to the different elements of the system to allow for a deeper understanding (see Fig. **2**).

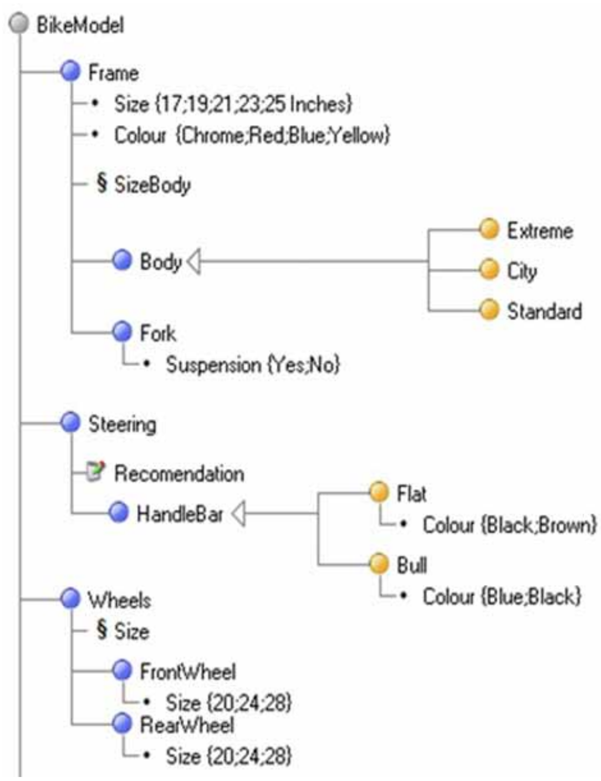

Fig. (2). Product Variant Master for a bike.

Through using a PVM for a bicycle, it becomes much easier to see the company's range of products and whether some components might overlap; maybe some of the bikes could use the same components as some of the other bikes. This leads to a substantial increase in knowledge of the company's different components, along with their properties and relations. This increase in knowledge can then be integrated into a configuration system. The configuration system makes it easier for customers to choose among viable solutions and customize a bike to their liking through a software interface.

In order to move from the idea of using a configuration system to successfully implementing it, seven steps should be followed. First, the commercial aims of developing and implementing a configuration system should be clarified. This clarification can often be accomplished by using a gap analysis to show the expected improvements to be achieved through the use of a configuration system. The second step constitutes an analysis of the product range, typically involving the use of a PVM. The third step is object-oriented modelling, where the method to be used to display the findings from step two is determined. Step four, object-oriented design, constitutes selecting the software to be used, adapting the object-oriented model to the software, and specifying the programming requirements. Step five is the programming of the configuration software. Step six constitutes implementation of the software in the organization; and in step seven, the configuration software is maintained and further developed [1]. Step six and seven were not relevant for this project, since it is a research project.

The configuration system makes decisions based on constraints and attributes that are interrelated through logical statements. The logic in the program enables the programmer to define solution spaces for the user, thereby guiding the user to a viable solution while giving the user the opportunity to affect the solution, thereby living up to the principles of mass customization. The constraints are based on the answers the user gives to questions using binary or n-value variables. The answers are then related using "and", "or" or "neither nor" rules. Hereby, the number of possible solutions is reduced, ensuring that the solutions given to the user satisfy his requirements.

FLS has been used as a reference tool in order to compare the case company with another company in testing the hypothesis (see the hypothesis section). FLS is a company that constructs highly complex, custom engineered cement factories. The company has more than 13,000 employees in offices in more than 50 countries around the world. FLS has been the leading supplier to the global cement industry since the late 19th century [10]. As a bid to simplify the earliest processes of manufacturing cement factories, FLS has achieved a more efficient sales and engineering process through introducing mass customization principles [8], which allowed a radical redefinition of the company's product architecture. FLS has successfully implemented a configuration system based on a top-down view of their product range, which enables them to improve quality and the amount and speed of tenders delivered to potential customers. The hypothesis is based upon the complexity, size and number of projects FLS has.

METHOD

In order to test the hypothesis, a series of steps were used, inspired by the article, "Building theories from case studies", [11] and Action Research theory [12]. A scenario/hypothesis was formulated based on FLS' experiences. This was done through a four-step cycle, based on Action Research theory. The four steps are Plan, Action, Observation and Reflection [12]. These steps are not taken sequentially but partly parallel, where planning and reflection are combined in the fourth step. This is done in order to use an iterative approach to make the scenario as correct as possible with regard to the given problem domain. The way this was achieved in our study was to formulate a hypothesis based on the experiences from FLS and then form a scenario. The scenario was also made in accordance with the idealistic model, "the good process", as formulated by the Danish Construction Board [13]. This was then tried out in a construction company. Throughout the process, much iteration were made to adjusted the plan and action; however, since this is not the main topic here, it will not be discussed further.

The research undertaken in order to verify whether FLS' work and success are comparable and possible to transfer to the construction industry has been primarily based on interviews with professionals from this industry. Knowledge about the area of mass customization from other industries enabled us to focus on gathering information from these professionals, and through the application of the theories, to derive potential areas for improvement. Throughout the six-month project, more than 35 interviews were conducted, and a workshop was held with 16 different professionals from the construction industry and lectors from DTU.

The workshop showcased the findings in order to receive feedback from the various professionals involved in the project. Thus, it was possible to use the professionals at the workshop to find out whether our findings were correct and to make improvements. The workshop worked as a means of iterating. The general attitude among the professionals at the workshop was one of openness; they were very willing to answer and ask questions. An introduction was made presenting the information gathered and the results so far, in the form of the configuration system. The input gathered at this workshop was used to fine-tune the configuration system and make it clearer. Through the workshop, values and criteria were gathered to make a cost-benefit analysis in order consider the scenario from a more economic point of view.

We then looked at different cases and articles that would be beneficial to use as background for proving or disproving the formulated hypothesis. It was decided that FLS would make a great starting point, and that NCC should be the dominant case. After studying FLS and the case company, we wanted to set some starting points for validating the hypothesis. This was done through defining a scenario to be used throughout the project, based on the experience gained from FLS. The knowledge necessary to specify this scenario was obtained through the above-mentioned sources, interviews with professionals in the industry, as well as relevant reports [14, 15]. These reports primarily used a bottom-up approach to the construction industry in attempting to apply the principles of mass customization. The knowledge gathered was systemized using a PVM (see Fig. **3**). In this project, only the Customer and Engineering views were used due to the nature of the research, which was to look for general concepts and not specific parts.

After systemized knowledge was gained, it was programmed into configuration software, and a configuration system was constructed. The reason for using a configuration system was to visualize and test the gathered information, as well as to present the configuration idea to people not familiar with mass configuration concepts.

HYPOTHESIS

The complex task of applying the principles of mass customization to the construction industry can be related to the FLS case [8] of implementing a configuration system in the construction of cement factories, which was based on a top-down approach with regard to product range. FLS describes its product range on a conceptual level. This means that FLS does not describe exactly what is needed in the smallest detail or exactly what should be used in order to construct a cement factory. This allows FLS to give relatively precise cost estimates very quickly when making a sales bid for a new project [8]. Breaking down the product range into its smallest details, however, is the most typical way of using the principles of mass customization [1]. But what FLS does is to give their customers some conceptual, general choices upon which to base decisions. Thus, a set of specifications is defined that the cement factory must adhere to, but the specifics of the factory can be determined at a later stage after an agreement has been made. In this way, FLS gains the ability to give fast and relatively precise cost estimates without having to design a completely customized factory that considers special specifications set by the customer every single time it makes a bid; FLS can reuse a lot of the same components, and knowledge, already used in constructing other factories.

The reasoning behind introducing these measures to the construction industry and making buildings more standardized is to move the customer order decoupling point (see Fig. **3**). This is the point at which the process changes from a standard, made-to-stock process to a customer-specific process that makes the product individual. Hereby, more of the building is within a set frame, and only the important visible components can be differentiated by the customer.

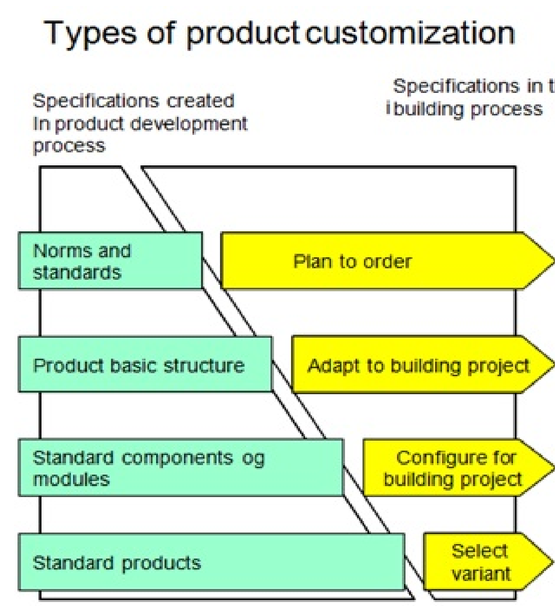

Fig. (3). Different spots for the Customer Order Decoupling Point.

Thus, the customer is allowed to choose between different predefined components and technical solutions, instead of receiving a proposal from the construction company that describes the ideas they have for the construction. This helps to make the building construction faster and cheaper and gives the construction company the opportunity to optimize the construction and installation of the different components.

When FLS commenced development of a configuration system, they started by analyzing their product range. Through a great deal of analytical work, they managed to break down their factories into modules from which they constructed a configuration system. They described their modules on a conceptual level, as the modules are quite diffuse and complex, so the customer does not know exactly what they are getting. They just know that their factory is within the guidelines they set out from the beginning.

The knowledge necessary to develop a PVM [1] and configuration system was obtained through interviews and a workshop at the construction company. It was decided to focus the project on construction of residential and office buildings more than three storeys high. This focus was chosen due to the great complexity of these buildings compared to single unit houses, but also because the case company's focus is on this sector.

Based on the information collected in the PVM, a configuration system was created. The configuration system allows for the information in the PVM to be correlated by using logical statements and a Graphic User Interface (GUI). After developing and implementing such a configuration system, it becomes much faster and easier to work through the early phases of bidding and winning a quotation. This is because the configuration system presents the most important decisions, including the bulk of the final costs and effects of any decision taken, while supplying guidance to the user.

The configuration program helped find missing information, especially constraints in the PVM, and made a clearer statement to the employees. In return, the improvements in the data obtained through the use of the configuration system allowed new and better feedback from the employees, resulting in improvements both to the PVM and the configuration system. The configuration system is constructed to move from the traditional (as-is) way of doing things to a more streamlined modern (to-be) way (see Fig. **4**). The configuration system will impact the beginning phases of the construction process and merge them together, due to the greater amount of information known earlier on in the process.

This will lead to better/more precise decisions in the early phases, which translates into cost reduction and quality improvement [10].

FLS was used as a reference case in order to learn from what they did and thus obtain a guideline for where to go next. This meant that we examined the construction industry in a top-down configuration of the technical solutions in order to obtain a conceptual overview. This was done in the periphery, however, so that if certain aspects were not suitable to the construction industry, they would not be force-fitted. The reasoning behind using FLS as a reference case was the similarities between its form of production and the construction industry. Both industries demand highly complex and few- of-a-kind products; however, there are several areas in which the two industries are quite different from each other. FLS is a worldwide company with about half the global market for cement factories, whereas NCC has its focus on Northern Europe. But even within such a comparatively smaller geographical area, many different materials, methods and building constructions are necessary. The factories FLS constructs are much more similar in comparison to the buildings NCC constructs, since cement factory customers are not as interested in the aesthetics of the factory. This is in sharp contrast to the demands of NCC's customers, who want a building that expresses their image and their architectural aspirations. In spite of these differences and due to the several aspects of the two companies' products that are very similar, we believe that the two companies, along with their respective industries, are comparable.

CASE STUDY

Throughout the project, a series of interviews were conducted in order to gain the information and knowledge necessary to construct a PVM and a configuration system. The information was put into the PVM as it was gathered. Based on the new information in the PVM, new questions were raised and new interviews were made. When the information in the PVM was deemed sufficient, the project entered a new phase – the creation of a configuration system. The configuration system was chosen due to its ability to communicate information and help the user make guided and sound decisions. This is done through the configuration system's ability to include or exclude questions and solutions based on answers to questions asked at an earlier stage of the configuration.

From the knowledge obtained through the interviews, we concluded that the most important areas to examine were the larger parts of a construction project, i.e. the static system and the installations. The static system refers to the skeleton of the building: the supporting walls, columns and facades (see Fig. **5**). All of the gathered information was distributed and analyzed in a PVM. This tool is useful for organizing the product range and obtaining knowledge about what the company produces and what the rules are regarding how to put them together. It is a great way to start the preliminary phases of constructing a configuration system, because it ensures that most of what is important to include in the

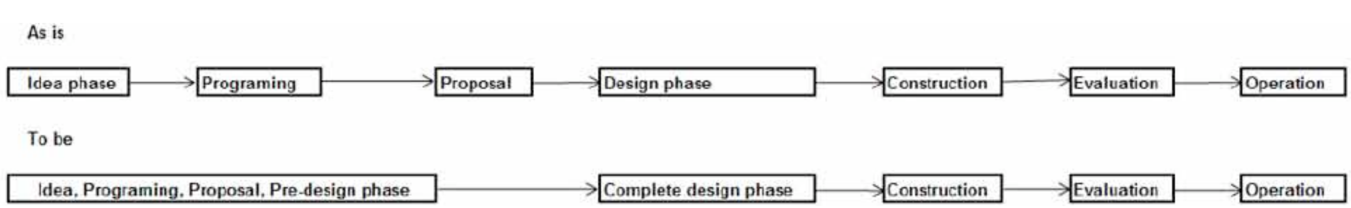

Fig. (4). Impact of the configuration system.

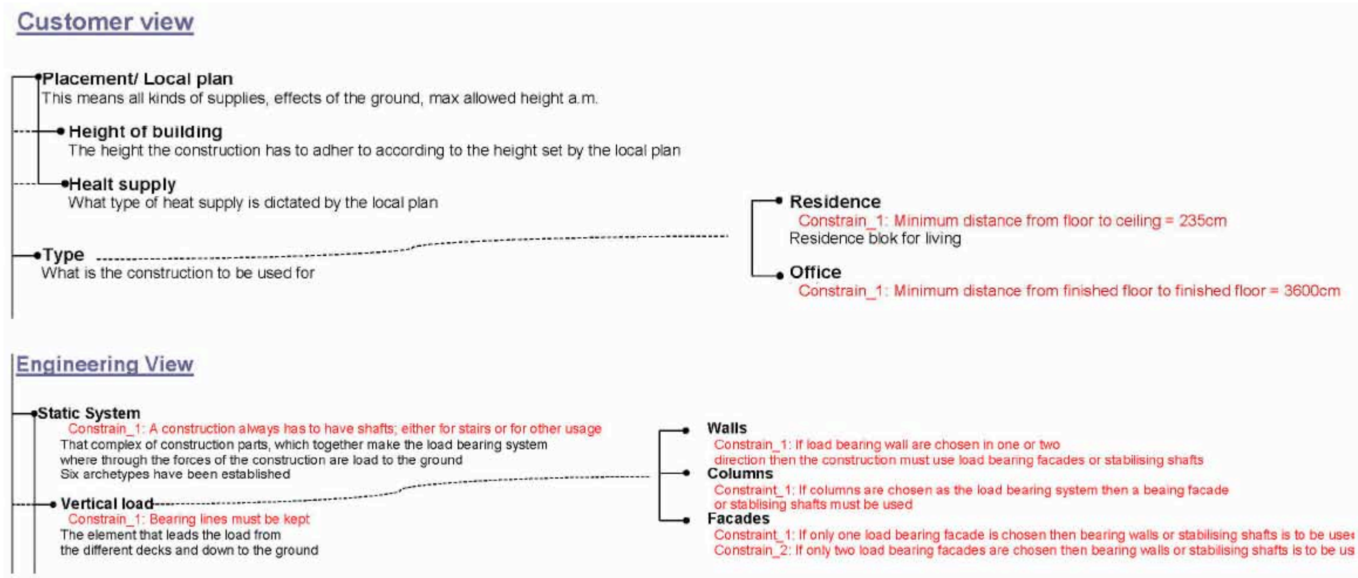

Fig. (5). Cut-out of the PVM, these portraying parts of the customer view and the static system in the engineering view.

configuration system is also included in the PVM. The cut-out, shown in (Fig. **6**), shows parts of the customer and engineering view. This shows that choices made in the customer view directly influence the engineering view.

The installations refer to the more crucial installations. These were found to be ventilation, tap water, sewage, heat insertion and electricity. The ways these different installations are led through the building are also included (see Fig. **6**). In Denmark, installations such as water, electricity, sewage and ventilation are normally installed together in centrally placed shafts, making one centralized system for the entire building.

The reason for including these different variables is that the information gathered favoured these areas, and also that these variables contribute most to a construction project's costs. They also constitute a large part of the construction that needs to be planned at an early stage in the construction process, due to the nature of the parts that constitute the skeleton of the building. Relatively high costs are connected with having to change any decisions regarding the skeleton at a later stage.

All the gathered information and data was put together and displayed in a PVM so that it was possible to elicit many illustrations and cause/effects relationships and break down the different technical solutions. As shown in the figure above, much effort was given to just describing the most comprehensive of the different technical solutions and not dwelling on every single detail. This was in accordance with the profound top-down approach being attempted.

Other construction projects previously conducted by the case company were included in the analysis of the construction industry in order to study economic aspects. Thus, their own experience was used to construct this new configuration system by examining three different projects with three very different cost bases, i.e. one expensive project, one average and one inexpensive.

Static System

The static system used in construction is normally based on several principles, such as maintaining stability while meeting the spatial proportions wanted by the customer (see Fig. **7**). One focus of the project was on defining archetypes of static systems used in residential and office buildings.

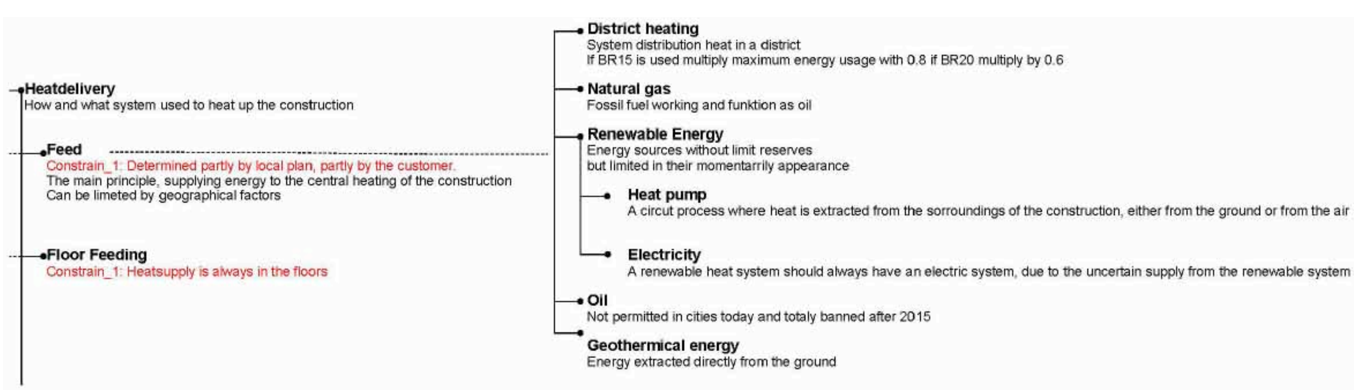

Fig. (6). Cut-out of the PVM, this being the ventilation system, part of the installations.

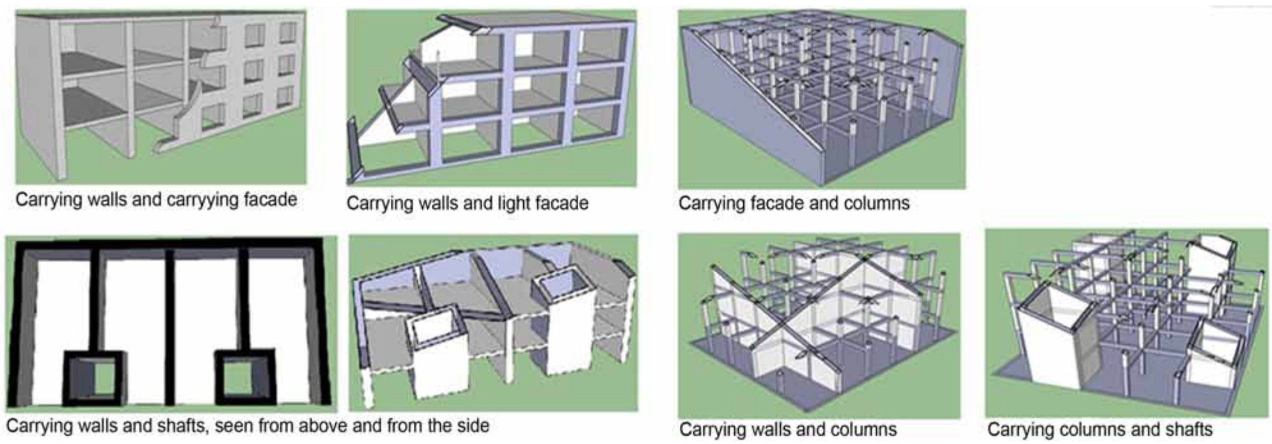

Fig. (7). Overview of the different archetypes identified

This resulted in six archetypes made from combinations of pillars, shafts, walls and open or closed facades (see Fig. **7**).

These six archetypes represent the general combinations used when designing the static system of a building. Although it is possible to define six archetypes, it is clear that they are typically not used exclusively but in combinations, depending on the function of the building.

Some aspects of the static system were omitted, Especially the more abstract aspects of a building, such as shape and architectural expression are difficult to include, because of the subjectivity of their perception.

Installations

Through an analysis of the different installations necessary during construction, the focus on the various installations differed. It was decided to include ventilation, which consists of feed shoot, ventilation conduits, ventilation principle and air recycling principle; water and sewage; and heat supply, which consists of feeding and heat transfer and electricity (see Fig. **8**). These installations were given different degrees of attention due to differences in importance. One of the most important installations is ventilation, due to its size and complexity with regard to both the number of systems and also the dimensioning of a well-functioning system. Water and sewage are almost just as important, due to the fact that they are most often connected near each other, where regulations require that they are close to the installation shaft. Heat supply was addressed more than water and sewage but less than ventilation, due to the effect the heating system has on energy consumption. Electricity was only addressed briefly, due to the lack of effect on energy consumption and the placement of power plugs.

One of the greatest challenges in systemizing installations was to decide what to include and what not to include. The final choices were made based on the impact on the final building's energy consumption and the availability of information from professionals at NCC.

The major challenge in this area was gathering information. It was difficult for the different professionals to look at their respective domains and simplify them so they were applicable to a PVM and a configuration system. By changing the questions and asking people about other peoples' domains, it became a lot easier to achieve a simplified view of the respective domains and thereby get them confirmed by the different professionals in charge.

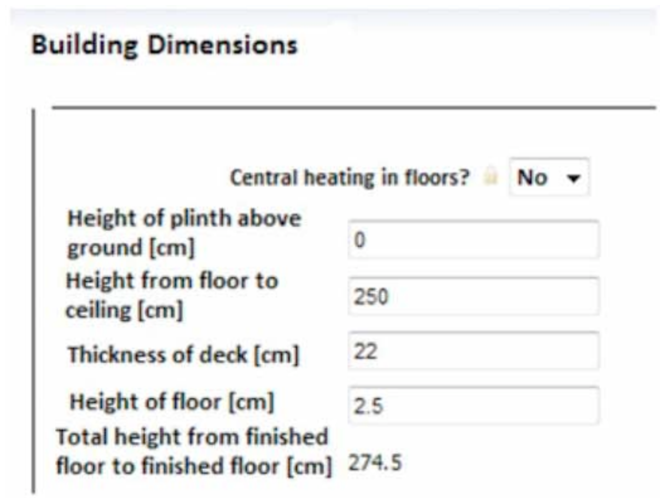

Fig. (8). Cut-out of the configurations system.

Building Parameters

When all the different input is put into the PVM and the configuration system, all the different parameters can be put together so they can work together intelligently. This means, for example, that when the number of stories in the building , the thickness of the floors etc. are typed in, the configuration system can calculate how tall the building will be and whether this is in accordance with the previously defined local limit. Then, the results obtained from the data put into the system can be discussed.

Height of Building

Several steps were taken to ensure that the local plan requirements were adhered to. One step was to ensure that the height of the building was not more than the maximum allowed by the local plan. This was done by means of an equation (see below), which sums the different elements that constitute the height of the building, and then compares the result with the maximum height allowed by the local plan. This equation then determines whether or not the building should be changed in any way so as not to violate the maximum allowed height.

$Height\ of\ Building$ = Y+,X=0-X-,R+N,Q,V.+D+G(Q).+ I+T+K+H.

When enough data had been gathered, we started developing the configuration system. We found the configuration system needed a different layout, comparable to the PVM, so that the user's answers could be used repeatedly and the user would not have to answer the same question more then once. The changed layout also gave the user a sense of getting closer to the building by starting with the local plan in the first questions, then moving closer to the building, and ending up with questions regarding ventilation and the like.

Energy Consumption

The energy framework was examined due to the great amount of government regulation in this area. This was done by just using estimations and rules of thumb. In order to decide whether or not a building complies with regulations, a series of guidelines are available. It is difficult to estimate precisely whether a building follows these guidelines or not, but today, the calculations are carried out by professionals using software simulation. In the project, it was decided to use recommended values for heat transfer through different parts of the envelope in order to estimate if the specific part was within the general guidelines. These estimations were drawn from the Danish building regulations [11], but they do not ensure that a building is within the legal energy limits. Usually, they do ensure that it is only necessary to change minor details in order to comply within the regulation limits.

Economy

The three areas deemed most applicable in order to obtain a differentiation in costs were facade, geometry and outfitting. This was achieved through three different price estimates for each of these three areas, which gave a total of 27 different combination possibilities. It is thus possible to give estimates of the cost of different parts of the building. It soon became apparent that it was difficult to arrive at more precise estimates of the cost of different construction parts due to the many parameters that affect them – e.g. for a façade: height from terrain, size of parts to mount, angle of façade, material used, and many more.

The different professionals at the case company found these price estimates quite difficult to grasp, since they were not able to simplify their domains in order to make examples for the configurations system.

THE CONFIGURATION SYSTEM

Fig. (**9**) shows a representation of the configuration system. The user is able to enter different wishes regarding the height of the different elements that constitute the height from one floor to the next – e.g. the height of the room, the deck and the floor. Based on these wishes, the configuration system gives the user the total height from one floor to the next. These choices can be pre-entered by the programme to allow the user to correct the heights only if he wishes to do so. The programme also supplies explanations and guidance while the user is making his decisions.

Fig. (**10**) showcases a message from the configurator that indicates that one of the questions was showcased (in this case, what type of building the customer would like – residential or office). There are many questions to be answered when running a session in the configuration system, but many of them are constructed so that they can be deemed not important or removed due to a lack of knowledge at that point in time.

EVALUATION AND EXPECTED BENEFITS

Of the different scenarios for implementing a configuration system at NCC, one was deemed to resemble FLS most and to fit well with the standard processes used in NCC's construction process. This scenario was then subjected to a cost-benefit analysis (CBA) in order to showcase the learning curve and the possible revenue gained by NCC through implementing a PVM and configuration system. It was found

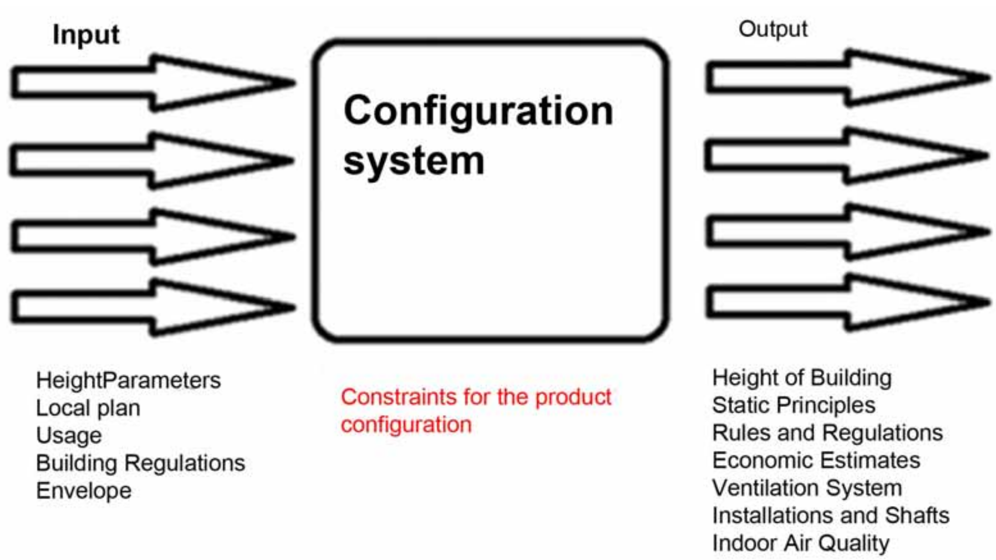

Fig. (9). How the configuration system works.

through estimates made at the workshop that it would not generate revenue, at least for the first years.

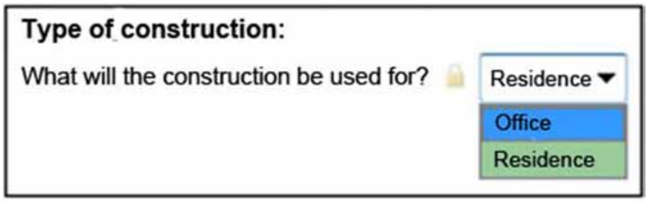

Fig. (10). Example from the constructed configurator.

The economic values used for the calculation of the CBA were gathered from the workshop, but the cost of the software was taken form the FLS case [5], and set to be approximately DKK 250.000 (42,000 USD). In addition to this cost for software for developing the configuration system, it was deemed necessary to use four man years to develop the system.

After establishing costs and expected savings from implementing such a PVM and configuration system, we started discussing, the benefits that would result from implementing these tools, i.e. what we could expect the future to look like.

If NCC, through the use of these new tools, could win just one additional order every ten years, then the costs of implementing these tools would be paid for. If NCC, through these new tools, could improve their use of the different components, then they would use them better and make the installation or construction faster and more accurate. The new procedures would also help NCC reduce errors and uncertainties, learn about the possibilities for making different technical solutions, and showcase what the customer’s building would look like more easily.

Alternatively, the implementation and maintenance of the new tools and necessary procedures might be neglected or poorly maintained, which would cause NCC to lose its investment in the PVM and configuration system.

The results gathered in the PVM and configuration software were put into a matrix (see Table **2**), together with the results f in the FLS case, so they could be compared. This was done in order to estimate whether or not an introduction of mass customization principles in the construction industry could have the same positive effects as experienced in FLS.

By the structure of the process is meant that the guidelines used in the process are all known so that no deviations occur, or at least very few. The possibility to show inheritance relates to the ability to see the effects of changing one part in the construction. Modularization relates to the extent to which the parts of the construction can be modularized.

From the evaluation, it was found that a configuration system would be a beneficial tool for the case company and the construction industry in general in order to avoid repetitive work, as long as it is properly integrated with existing ICT-tools. It was found that several areas have great potential for implementing a configuration system, while other areas present great hurdles.

Table 1. Definition of Variables

Plinth	Y
Number of Storeys	X
Room Height	R
Lowered Ceiling	N
Installations (w/o. Ventilation)	Q
Ventilation	V
Deck Thickness	D
Floor Type	G
Insulation	I
Roofing	T
Technical Room	H
Crown	K

Table 2. Comparison of FLS with NCC.

RESULTS	FLS [6]	NCC
Throughput times of constructions	Considerable reduction	Considerable reduction
Consumption of resources, human and material	Reduction of about 50%	Some reduction
Quality of tenders	More homogenous and with better quality	More homogenous and with better quality
Structure of process	Considerably more structure and minimization of risks	Considerably greater structure and minimization of risks
Possibility to show inheritance	Easier to showcase for customers	Easier to showcase for customers
Modularization, amount of repeated structures	Great extent	Less extent

The areas with great potential are colour coded green. We found that throughput times, quality of tenders and the construction process, the amount of structure, the means to showcase cause and effect, and the risks of the projects could be improved. We deemed that these areas would be impacted positively through the implementation of a PVM and configuration system that would make projects run more smoothly.

However, ´the amount of projects applicable to a configuration system´ and ´the possibility to incorporate modules in the construction industry´ comprised some hurdles in relation to implementing the configuration system. These are not a problem in the construction of cement factories, but they mean that the approach to a configuration system must be quite different from the systems in similar industries.

Despite these hurdles, it is still a beneficial tool due to the amount of positive tendencies on other accounts, but experiences from implementing the configuration system at FLS also show that the advantage is not just better results achieved in the building process; the benefit of developing a configuration system is also the extensive knowledge gained regarding product range and how different solutions affect and overlap each other. This knowledge can be used to simplify the process by reducing the number of solutions to projects, as well as reducing the number of parts through eliminating overlap.

In order for a configuration system to be useful in the construction industry, it is crucial to find a way to quantify the different demands and wishes of the customer. This was found to be one of the greatest barriers in implementing a configuration system in the case company. The customers in the construction industry tend to have wishes and demands that vary a whole lot more than is the case for FLS. A relatively large number of projects have to be configurable in order for a configuration system to become a useful and successful tool for the case company. The exact number of projects is difficult to estimate; it depends on the possible savings in resources versus the development resources required to develop and maintain the configuration system.

The possibility of modularization is a problem for the case company in comparison to FLS, due to the fact that all the different components used for constructing a building are entangled – they all depend on each other – and many of the parameters that go into constructing a building are subjective and depend on the customer's demands and wishes. In addition, the different building elements have an architectonic aspect, which makes it quite difficult to replace a module one-to-one [12]. This makes a building quite difficult to modularize compared to cement factories. FLS can split their factories into a bunch of smaller components and connect them through various interfaces, which is not applicable to the construction industry. It is relatively easy for FLS to configure a new factory based on the customer's wishes and demands regarding capacity and energy consumption. This is because the different parameters used in the calculations for the factories are all quantifiable, objective goals, compared to the subjective wishes and demands customers have in the construction industry – such as architectural demands [13].

Because the construction industry has a more open framework regarding what a building can or should not do in relation to architecture and the customer's individualized wishes, a greater degree of quantification is difficult. This makes it particularly difficult to develop components, because it is important to know which parts a customer, or the construction company, can quantify in order to achieve a satisfactory degree of variation of buildings, and thus increase saleability. This is a problem in regard to architecture, because greater modularization could easily have a negative effect on the possible variation and thus compromise architectural freedom.

DISCUSSION

Through the data gathering and analysis, several issues connected with implementation of mass customization in the construction industry became apparent. People were in general positive towards the idea, but they often had a biased view of the possibilities. This became apparent when different professionals often suggested that their co-workers' areas could easily be standardized and benefit from implementation of mass customization, whereas their own areas were too complex and never used any kind of standard solutions.

Through the work with the project, it was discovered that some areas are harder to implement in a mass customization context than others. These differences are most often due to difference in expectations and demands for diversity that the user or buyer might have.

Although some areas of construction might differ in relation to expectations and demands for diversity, other areas are of no importance as long as they function properly – e.g. the static system or installation, which are often not clearly visible in the finished construction. People often have a lot of subjective demands regarding other aspects, however, especially the architectural aspects such as the geometric shape, the perceived façade expression, or the look of the building. These subjective demands are hard to grasp and indefinable, and therefore customization based on equations and logical statements make these aspects difficult to implement.

FLS is a global company with relatively similar products, since their factories are in many ways the same, only varying in capacity or other quantifiable measures. This is easily illustrated by the fact that these factories' customers mainly state their wishes in two areas: the amount of cement to be produced per year; and the maximum allowed energy consumption. Due to the minimum of customer demands, FLS, has a larger domain within which to find solutions where they are in charge of all the other parameters. In the case company, however, customers have many different and varying requests for a building that can relate to interior design, the facade and so on.

The different elements of FLS' development of their configuration system can be translated into a configuration system in the construction industry, subject to the different subjective standpoints and opinions. Despite the results for the two criteria (Table **1**), ´tenders´ and ´modularization´, we consider it beneficial to develop and implement a configuration system in the construction industry. This view is supported by interviews conducted throughout the project in which the interviewees express a need for a configuration system.

The different employees had a hard time finding standard solutions within their respective fields, even though they find a configuration system to be a good idea. The reason for this lack of ability to see standard solutions in their own field might be that these people have too much in-depth knowledge of their field and therefore have a hard time looking at the bigger picture; or maybe they just want to protect their jobs. In relation to other fields within the construction industry, however, they found it much easier to stay on a more superficial level.

CONCLUSIONS

When conducting the interviews, it became clear that the different professionals had a biased attitude towards the idea of configuration in the construction industry. Generally, the professionals were positive towards the idea and very helpful when they gained an understanding of the project, but often the areas where they saw potential were not the areas they worked with themselves. One professional saw his area as too complex and detailed to generalize in any way, or at least only in very few areas, whereas the areas of other professionals often seemed easier to generalize and use in a configuration context.

It is assumed that this difference in attitude can be explained by the following two factors: First, people have extensive knowledge in their own field and might therefore have a harder time generalizing solutions. They are aware of the smaller differences between projects, whereas in other areas they only possess knowledge of the main components or bigger parts of the solutions. Second, most people do not like the idea of their job being standardised or taken over by computers or employees with less experience and qualifications. They are therefore protective when people bring up such subjects; however, in this case study, this was not experienced.

Through the use of the different technical solutions, it is our view that a suitable configuration system, for use in the early stages of a construction project, can be successfully developed. This can be done using a top-down approach for the technical solutions in the construction industry. It is shown that it is possible to describe these larger elements on a more conceptual level. Thereafter, it would be beneficial to look at the different elements using a bottom-up view, in order to describe these elements in greater detail.

CONFLICT OF INTEREST

The author(s) confirm that this article content has no conflicts of interest.

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