MODULARIZATION—A THIRD APPROACH TO MAKING CONSTRUCTION LEAN?

Sven Bertelsen[1]

ABSTRACT

Every construction project is characterized by being complex. This complexity causes high variability in the flows and one approach to mange this kind of production is to use situation based management approaches such as Last Planner. However, another approach is to reduce the complexity of the site production by turning the building into a product, which can be manufactured in permanent facilities, where lean production is usable and make the site-work an installation mainly. This is seen in the manufactured home industry. In recent Danish discussions these two approaches has coined these two different approaches 'the process strategy' and the 'product strategy' respectively.

However, a third approach to making construction lean is modularization. By this the complex system is divided into easily manageable and clearly defined functional modules than can be developed, designed, manufactured and installed as small scale projects in an easier to manage assembly construction process. This approach has since IBM's ground breaking modular development of the 360 series of computers proved a very fruitful route to manage complex product development and manufacturing.

Experiences from a full scale Danish development program indicate that the benefits of modularization observed in manufacturing may also be obtainable in certain parts of construction. Looking closer into the development of the construction process reveals that modularization already exists to some extent, but that the potential benefits of this approach have not at all been explored and a few only have looked in detail into the nature of a construction process based on such systems.

The paper investigates the process and the product strategies to managing complexity in construction and suggests a third strategy based upon the use of modularization. It proceeds by looking at the IBM 360 development process and not least its consequences for the computer industry, and it then presents some ideas on how an approach to modularization in construction may be made.

KEY WORDS

Modularisation, complexity, prefabrication, manufacturing, management

INTRODUCTION

Every construction project of any significant size forms a complex and dynamic system (Bertelsen 2003a). Such systems have characteristics which often surprise observers having a background in the ordered Newtonian world and therefore believing that managing projects by managing the transformations only may be possible (Koskela and Howell, 2002). The result is management principles with an outset in the ordered world, where reductionism is the way to understanding systems and solving problems: 'The whole can be explained by understanding its parts in an adequate detail.' But in the world of complexity this is not the case. The whole is more that the sum of the details, the system behaviour can not be foreseen by looking at the details only and unruly phenomena such as chaos, self organization and emergence are parts of life, but most often project management is not based on this understanding of the nature of the construction project.

This misunderstanding of the nature of construction may be an important reason for the construction industry's bad performance. Unforeseen events, cost and time overruns, accidents and errors are the rule rather than the exception, and increasing project control, quality assurance and

1 Sven Bertelsen is a Danish management counsellor within the field of Lean Construction (sven@bertelsen.org)

safety procedures do not seem to improve this unacceptable situation.

Bertelsen (2003b) discusses this complexity from three different perspectives:

- The unique product and thereby its value defined in cooperation with client and its associated process;
- The temporary production system;
- The social system established for the purpose at the construction site.

Accepting complexity as the nature of the construction process, different strategies seem to come up:

- Develop methods to better manage this complexity
- Reduce the degree of complexity
- Make the complexity easier to manage

This paper discusses different approaches often used and tries to reach a new one through modularization. The paper is indeed more an essay based upon little research, quite a bit of reading, more personal experiences and a great deal of thinking, than a real scientific paper, and the background is first and foremost the author's own experiences from forty years' work as consulting engineer and project manager on a number of large projects up to US$ 1 billion but also some more modest projects aiming at the development of the construction process. Some of the ideas may therefore be relevant mainly in construction industries still based on the work of trades, such as found in most European countries.

The journey sets out by a brief review of often used approaches and it passes through the history of modularization in manufacturing on its way towards some thoughts on modularization of the building process with references to recent experiences from a Danish development program, trying out these ideas in practice.

DEALING WITH COMPLEXITY IN CONSTRUCTION

The complex nature of construction causes often great variability in the flows, not least the flow of work but also other flows such as information, crew, materials and space. One approach is to better manage this variability, where situation based management methods such as last planner have proven efficient (Ballard, 2000), (Bertelsen and Nielsen, 199//). Also methods dealing with the complexity within the social system has recently shown their value (Macomber and Howell, 2003 and 2004, Elsborg et al, 2004).

Another approach is to reduce the complexity, not least that stemming from the individual product and process by making the house more like a manufactured product as seen in the manufactured home industry.

In recent Danish discussions on the development of the building process (Projekt Hus, 2001) these two approaches have been coined the Process and the Product strategies respectively. The two strategies are briefly discussed in the following with an aim of identifying a third approach: modularization.

THE PROCESS STRATEGY: MANAGE THE COMPLEXITY

An often used approach in dealing with process complexity—in construction as well as generally—is to divide the problem in question into sub-problems, which can be solved independently, expecting that these solutions jointly provide a (near) optimal solution to the problem in question. This reductionistic approach may be right in some cases, but only with a low degree of complexity. Kauffman (1995) coins this approach to complex problem solution 'patching' but at the same time recognizes that not only the patches' sizes, but also their overlaps are of great importance for the system's capability to move towards the optimal solution. Kauffman's hypothesis is that the higher the complexity the deeper the overlaps between the individual patches should be. This leads to the recognition that with a high degree of complexity the optimal overlap might be so big that the benefit of dividing the problem into patches is almost lost.

In the construction process this patching method is used through the system of crafts albeit without a rational analysis. The design work is divided into design disciplines mainly and even though some of the design work is focussed on functional systems it is still a matter craft undertaken by trades just as the construction process usually is.[2] The patches are therefore practical ones mainly and not logical seen from a functions view. The problem solving within design and construction is thereby made an issue of transformation mainly. The use of last planner methods and other situation based management tools may keep the process under control but only to a certain degree.

Another approach often seen is to manage the complexity by moving more of the work into more stable production environments through off

2 The term 'Craft' is used here to describe a situation, where the parties are organized by their trade—or their materials—and where everybody within a trade in principle can do anything possible within that trade. Architects, engineers, carpenters or plumbers are all such trades.

site production. But still the work is usually undertaken as work of trades, where complexity from the individual product still exists.

Even though the patching combined with situation based management and off site production is working better than management by planning and control only, the system may still be unacceptable to the client because of its unpredictability, not least when compared to modern—lean—manufacturing. 'Why can houses not be produced in the same efficient way as cars' is an often heard question. And the product strategy is the obvious answer.

THE PRODUCT STRATEGY: REDUCE THE COMPLEXITY

Another approach in dealing with complex problems is to reduce it and thereby make it easier to manage. Mass production in general has since Adam Smith been guided by this approach, which in its nature leads to specialization, standards, formalized procedures, factory physics, production control systems, and—at the end of the day: Lean Production. Every step along this route aims at reducing the complexity and establishing an ordered and foreseeable local situation with as little variability as possible. It has been argued (Vrijhoef and Koskela, 1999) that this route increases the total system's complexity, but this is dealt with through a much more efficient use of patching, and it seems that the need for overlap is reduced in this approach. Also the repetitive processes assist in taking hand of the complexity. The system has much better opportunities for learning. The results in manufacturing have been remarkable. Steady increase in product quality along with cost reductions. The source of our wealth is this approach, so why not in construction? Or rather: why not more? We do indeed see this approach within the manufactured home industry in the US, where the same quality of use per square feet is delivered to the customer at prices of down to one third of the price for a site build home.

Why then have these manufacturers not conquered the whole market in the same way as the car manufacturers have? One important reason for this is probably that houses—when in a group and in adequate number—become streets, squares or even towns and that we all have deep feelings about these emergent phenomena. We may admire a car or several types of cars when seeing them in the street—but living on a parking lot …! What we have is build environments where the whole is more than the sum of the parts.

Looking deeper into this we may find that the uniform product is satisfactory as long as one can not afford anything better, but also that increasing buying power makes the market ask for more individuality but not at much higher prices—mass customization, or even better, individuality, please, but also the capability of suiting the community!

MODULARIZATION—A THIRD APPROACH

Looking closer into the construction process one finds behind the scene a movement towards products undertaking a specific and clearly defined function. More and more construction materials turn into being systems, designed, manufactured and installed under a single contract. The elevators were probably the first, but now—in Denmark we see prefabricated bathrooms and roof sections, just as the facades and kitchens has been turned into systems. This development is in its nature a movement from the process towards the product strategy. The need for patching in dealing with the total complexity is reduced as the subproblems are encapsulated and solved within the individual systems.

More and more site production becomes based on such systems instead of the work of trades, and the standardized mass fabricated systems become more and more customized. The author proposes that these two lines of development will eventually converge in the format of modularization. An optimal delivering of value through individually designed, produced and assembled modules with the efficiency of the mass production.

But what is the nature of modularization and—not least—what is modularized construction?

THE CONCEPT OF MODULARISATION

My Concise Oxford Dictionary says about modularization: *'Module, n. Standard, unit for measuring …'*[3] This understanding of the term has since its introduction in the Danish building process in the late 1950s also been the common industry thinking about module. The initiative to modularisation in this sense was taken within the domestic housing sector by a coordination of preferred measures in the building design—vertically in 1953 and horizontally in 1960, which opened up for a tremendous growth in the manufacturing of building components such as prefabricated stairs, facade elements, windows, doors etc (Nissen, 1972). To this came the national building code making it possible to use the same components and systems nationwide.[4] However, these on the surface simple measurement rules were not what they looked liked only—they were the beginning of a transformation of the whole construction industry. Very few seemed to observe it, but the impact was tremendous. Productivity went steeply up and construction time went down, along with a surprising increase of the quality of the output (Bertelsen 1997).

The reason for this was the quite simple coordination of measuring units, which changed a substantial part of the construction from craft to manufacturing. The measurement coordination opened up for prefabrication of components on a large scale and common building codes opened in the same way up for a nationwide market. The competition turned from being on costs of manhours only into being a competition on functionality *and* cost. There was also all of a sudden room for competition on new product lines and higher value, often at even lower cost. The customer got at the same time the option of knowing what she was buying, before it was delivered. A great deal of the construction process was turned into being—not lean construction—but lean production.

The outcome was a giant step forward in productivity over a short span of years. Even though the goal in many European countries was quantity, also quality was substantially improved. However, this momentum was—unfortunately?—at least in Denmark lost in the slipstream of the 1968 uproar against everything uniform. The construction process was just on the brink of being able to deliver the desired individualism, but—sic—five years too late. Construction went to a great extent back into being craft (Bertelsen 1997) and without the benefit of knowing the methods of Lean Construction.

One may ask, whether this development was modularization in the meaning used in this paper. The answer is probably that it was in some products but also that the construction industry did not understood it as such, but merely saw it as off-site production of project specific components combined with prefabrication of common used components such as doors and windows.

THE IBM APPROACH

However, in these days measurement coordination is not the real challenge of a modular approach to construction and the term modularization has also since then gotten a complete different meaning; so let us once again turn to manufacturing for inspiration.

Baldwin and Clack (2000) state that complexity and modularization goes hand in hand and that the revolutionary break through in computer production was the development of the modularized IBM's 360 series of mainframe computers in the early 1960'ies, which changed the world of computer manufacturing and opened up for the success of the development of the PC twenty years later—also lead by IBM. How come? IBM has never had a reputation for being front end in product development. State of the art technology is most often developed by garage enterprises, but in setting a standard IBM has often proven to be master of the game, as was the case in the development of the 360 computer. Could it be that IBM in its nature is not inventors but organizers?

Until the 360 computers originally were products designed and build to customer needs. Later they became systems assembled to the customer's specifications—but within the limited range of options, offered by the vendor only. Any type—indeed any single copy—of a computer was still a 'closed' system with very little flexibility. IBM's revolutionary new approach was in their design to break down the computer system into functional units—CPU, central storage, tape station, disk drive, key board, card reader … *and to standardize the interface between these units and their operating software*. What they did, was to encapsulate these units as black boxes by—so to speak—stating that 'we don't bother what you do or how you do it, at long as you do, what the rest of the systems expect you to do as defined by the rules of interface.' This black-box approach gave a tremendous freedom in design, but was very difficult to organize, because the interface design—

3 The word modularization is not mentioned at all.

4 ISO made the measurement coordination an international standard by their 1006 standard (1973).

simple as it may sound—was surprisingly difficult to get through (Baldwin and Clark 2000).

However, once succeeded the benefits were enormous, albeit for IBM not to the expected degree. They were foreseeing an easier route to further development of their 360-product line, and that they got. But what they didn't foresee was that the modularization made it easy for competitors to offer 'plug in' components to their systems. And so they did. Not least break-out groups from IBM's own development team.[5]

Without going much deeper into the fascinating history of modularization one may point at the car industry, where cars—like computers—have turned from being individual products into being assemblies of modules made by specialized suppliers. The Dell concept of 'building your own computer' has not yet come to the car delivering process, but mass customization has not at all reached its peak either. The Value aspect of understanding production is still the prevailing one, so we may expect further development within the manufacturing industries in this direction. But how should one approach this kind of modularization in construction?

Before answering this question one may ask, is the IBM approach the right one for construction?

APPROACHING MODULARIZATION IN CONSTRUCTION

To modularize and manufacture houses may be fairly easy—but how to manufacture build environments worth living in? You may modularize your product and maximize the value for costumer but how does your product deal with the joint value of a nice built environment? What we have to aim at in the construction modularization process is systems where the houses are composed by modular components, but components that are able to accommodate to more than their neighbour components within the product, but to their neighbouring houses as well. A modularization of the building process may therefore be even more difficult than the one IBM undertook at tremendous costs in the development of the 360. In this it is necessary to recognise the nature of modularization. Modularization is obviously not about measurement coordination only anymore, it is a discipline of thinking, design and manufacture by function instead of trade. The key question is: What should this module do and how should it interact with other modules, before asking: How does it perform its objective and how do we make it. In doing this it is mandatory to understand and to design the whole as a total of functions instead of an assembly of materials.

An innovator taking up IBM's role and making an approach to offering modularised construction should probably forget most he knows about the construction process and make a completely new start. Modularization should be a manufacturing thinking, but with an outset from the output of the construction industry.

HOW TO THINK[6]

The key issue in this new process will not only be to know how to produce but how to deliver value to the customer as well. In doing this it is important to understand the community and the market as a built environment, and to set up a system of modules able to fit into this often very local environment.[7] An approach may be to clearly distinguish between the visible and the invisible building and to standardize the latter while keeping the former open for project customization.

This leads to the question of how to modularize. The usual way of thinking in construction in to understand the building as composed of the structure, the envelope, the internal completion (floors, ceilings, dry walls etc), the piping, the electrical systems and the completion work. Looking closer, this division is often that of trades mainly, whereas modularization must take place as much as possible in terms of functions. The building must be seen as a sum of modules each encapsulating a specific function with a standardized interface to the neighbour modules, allowing for competing manufacturers and models of the module.

Also, a module is almost never the output of a single trade but must be seen as a product designed and manufactured by a number of different trade experts and most often installed at the site by the manufactures' own, specially trained crews.

A problem here may be the interlock situation. It is hard to design modular buildings without having modules on the market, but the manufac-

5 Surprisingly IBM made the same move twenty years later by their PC, which even came with open specifications, which once again opened up for break out competitors such as Compact and for an avalanche of start up challengers.

6 The speculation in this section is to a great extent base don the author's own experiences as manager of the Danish Habitat experiment (1995–2000), which is reported briefly in Bertelsen (2001) and in more detail in Bertelsen (2000)

7 Indeed, manufactured homes made in very nearby Sweden has a very hard time to get a firm foothold in Denmark even at very competitive prices.

turers may be reluctant to invest in designing modules without a market of modularized projects.

STEPS IN MODULARIZATION

The modularization process must set out by designing the whole system—a kind of building to be modularized.[8] This is something new to most designers in construction: To design a flexible system, as a composite of modules, aimed for a specific market segment, but without the benefit of a known customer in the form of a client. This calls for market surveys, system analysis and other disciplines well known to the manufacturing industries but little investigated by architects.

The next step should be to divide the system into modules: that is functional units or systems and to specify the rules for their interfaces. The division into modules may be easy but the interface design has proven a difficult task with a huge number of pitfalls. Key questions may also be how many modules, and which kind of module design may be acceptable in the product system from an over all point of view and which may not.[9]

This leads to a key question: How to organize? IBM's 360 and PC experiences point at the fact that one should organize by specialized and innovative subcontractors—or rather manufacturers and suppliers—mainly. The challenge is then to find the most suitable and to make them cooperate in a creative and inspiring development process where ideas from different areas of expertise fertilize the participants' creativity. And to do this without giving them a firm and protected ownership keeping challengers out of the future process

The management's focus should be to ask questions and seek solutions adding value by utilizing the new opportunities in the manufacturing concept and to avoid the parties thinking in terms of construction.[10]

Also the over all system flexibility should be the management's concern. Each module should be investigated in depth for its variation capability. Often a more flexible solution may in the long run be a better one than the one offered initially at the lowest cost. In this also studies of the effect of scale should be thought in. Some solutions being initially more expensive may in the long run prove the cheapest because they are better suited for mass production.[11]

Once the system and interface design is completed, the rule of the game changes. It is now a question of delegating the detailed product development and process design to the different parties. Probably initially without competition, but in the long run competing modules for the same function should be sought out.

An important issue in this is to make sure that the 'module owner' encompasses design, manufacturing and installation of the product and that a short feed back loop is established. Often design problems are not found until the installation process and such errors should immediately be fed back to the home office.[12]

However, the most important challenge to the management in this development stage is to coordinate and control the interfaces. Using a few modules in an otherwise craft made building process may be easy. Skilled crafts can most often take hand of the inaccuracies and fit in, but to make two modules fit together is a manufacturing skill, which most of us in construction do not posses by tradition or training.

Finally the challenge for the management is to establish a new kind of firm to manage the product delivery. Modularized building may sound just like another building process, but it is indeed not so. Modularized building is a completely new production process in its own right and one should treat it so with a deep respect for its nature, its peculiarities and its pitfalls.[13] But this is not the

8 The author's own experiences are from terraced public housing

9 A key question in Habitat was the heating system, where the traditional Danish radiator based heating of homes proved to be a great hindrance for the efficient delivery of prefabricated floors and walls, whereas a central air conditioning system even at higher costs might be a better solution.

10 Another example in the case of Habitat was the recognition that in the prefabricated bathroom—one of the modules—a wall size mirror was a more cost efficient solution than the traditional tiles and at the same time offering more value to the customer.

11 The Habitat a/c system is an example

12 Indeed, in some cases Habitat was able to make the feed back loop from the site to the design and manufacturing as short as one or two weeks, so that an unsuitable design solution observed at the site was redesigned and used in the production with one or two weeks delay only. Products already in the pipeline of cause still carried the first solution but still the effect was tremendous. Also because the site crews were motivated to pin point faults and suggest better solutions.

13 One pitfall observed in Habitat was the importance of even small design errors or unclear project briefs. When the client at the delivery of the first prefabricated bathroom observed a minor mistake in the design of the lighting fixtures, 60 more copies were on their way with no opportunity for changing the design. The benefit of

only reason for setting up new enterprises. The real argument may be that modularized construction is not just construction using modules, but a completely new construction process. The body who orchestrates this process is not a professional design firm. It is not a contractor either, and it is indeed not a manufacturer of the modules or the materials used. This not a matter of profession as much as it is a matter of attitude. The modularized builder should be the firm offering the customer a customized new building process based on manufacturing capabilities delivered by a stable supply team undertaking an ongoing systems' development. A Dell approach may be the best example for inspiration: Build your own house by your own design but with the use of our modules. The exterior and interior design of the building in question may be undertaken by the supplier's designer, but it may also be undertaken by the client's architect, albeit with due respect for the system's capability.

Thus the modular builder is the end of the manufacturing chain, but at the same time he may be the professional client's partner in delivering a steady and increasing value to *his* customers: The users, the owners and the society. The stable production system opens a new room for an ongoing industrial research and development process. And the marketing of the modularised concept based on the value-price ratio makes it possible to generate a higher profit than possible by just selling man-hours, which can be channelled into an ongoing product and process development.

DISCUSSION

Lean Construction is often seen as a project management approach aiming at improving site-level production planning and control and at the same time increase the value delivered to the client. However, the term *lean* stems from manufacturing where it in more general terms deals with optimizing the value stream in mass production where the costumer is known in general terms only (Womack and Jones, 1996). Bertelsen and Koskela (2004) put forward the question whether lean construction is really lean in the sense of Womack and Jones and argue that it is probably not but rather a project production approach in its own right even though is based on the same Japanese principles as used in Lean Production. Bertelsen and Emmitt (2005) take this discussion further by pointing at the complex nature of the construction client as opposite to the more anonymous costumer in mass production and they argue that this complexity may be an important cause for the problems within the construction process.

In this view it may be argued that modularization—just as the product approach—is not making construction lean in the Lean Construction sense but rather approaches to a more efficient construction process, and it may be argued that these approaches are more 'lean' in the meaning of Womack and Jones as they to certain degrees reduces the customer influence on the design and the process even though they at the same time offers more value in product quality and process flow.

Is that making construction lean? It is at least in the present understanding in the Danish construction industry.

CONCLUSION

This paper has tried to show that a re-industrialization of the production of—part of—the construction industry's output through modularization is feasible and a road that may lead to great benefits in terms of lower costs and higher quality.

However, the paper also argues that there may be several stumbling stones along the road. One such stone is to keep the balance between efficiency and monotony. Houses are not products only; they are important parts of our environment. This goal may be reached if it is made possible in the development process to maintain flexibility—keeping options open for the customer without additional cost. This may be the challenge for the individual modularized builder, whereas the real threat—and thus the challenge for society—is to avoid that the benefit of scale takes over making the winner take all. A 'Bill Gates' in construction design would be a true disaster!

AKNOWLEDGEMENTS

The author wants to thank all the participants in the Habitat consortia and our partners in the development and production processes, not least then managing director Knud Erik Matz from Dansk Boligselskab for his always encouraging support of the concept and the governmental advisor to Habitat Mr. Keld Fuhr Petersen.

REFERENCES

Baldwin, C.Y. and Clark, K.B. (2000): *Design Rules—the Power of Modularity,* The MTI Press

this error was though that it led to an extensive use of 3d computer models to create a virtual environment for the customers to investigate before start of production.

Ballard, G. (2000): "The Last Planner System of Production Control", School of Civil Engineering, Faculcy of Engineering, The University of Birmingham

Bertelsen, S. (1997), *Bellahøj, Ballerup og Brøndby Strand—25 år der industrialiserede byggeriet.* ('Bellahøj, Ballerup og Brøndby Strand—25 years Industrialising Building'. In Danish). Danish Building Research Institute.

Bertelsen, S. (2000): *Habitat-håndbog,* ("The Habitat-handbook"). Erhvervsfremme Styrelsen

Bertelsen, S. (2001): *Lean Construction as an Integrated Production.* IGLC 9, Singapore

Bertelsen, S. (2003a): *Complexity—Construction in a new Perspective.* IGLC-11, Blacksburg, Virginia

Bertelsen, S. (2003b): *Construction Complexity Analyzes.* IGLC-11, Blacksburg, Virginia

Bertelsen, S. and Koskela, L. (2004), *Construction Beyond Lean: a new understanding of* construction management. IGLC 12, Elsinore, Denmark

Bertelsen, S. and Emmitt, S. (2005): *The client as a complex system*. Submitted for the 13th annual conference in the International Group for Lean Construction, Sydney, July 2005

Bertelsen, S. and Nielsen, J. (1997), *Just-In-Time Logistics in the Supply of Building Materials*. 1st International Conference on Construction Industry Development, Singapore.

Elsborg, S; Bertelsen, S and Dam, A (2004), *BygLOK—A Danish Experiment on Cooperation in Construction,* IGLC 12, Elsinore, Denmark

Kauffman, S.A. (1995), *At Home in the Universe, The Search for the Laws of Self-organization and Complexity*, Oxford University Press

Koskela, L. and Howell, G.A. (2002): *The underlying theory of project management is obsolete*, Project Management Institute

Macomber, Hal and Howell, G.A (2003), *Foundations of Lean Construction: Linguistic Action,* IGLC 11, Blacksburg VA, USA

Macomber, Hal and Howell, G.A (2004), *Two Great Wastes in Organizations—A Typology for Adressing the Concern for the Underutilization of Human Potential.* IGLC 12, Elsinore, Denmark

Nissen, H. (1972), *Industrialised Building and Modular Design.* The Cement and Concrete Association, London.

Projekt Hus (2001): *Ny industrialisering—et bedre produktmarked.* (Re-industrialization—a better market for products). Debathæfte 3, By- & Boligministeriet.

Vrijhoef, R. and Koskela, L. (1999): *Roles of Supply Chain Management in Construction.* IGLC 7, Berkeley CA.

Womack, J.P; Jones D.T (1996), *Lean Thinking*, Touchstone Books