LEAN CONSTRUCTION AS AN INTEGRATED PRODUCTION

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ABSTRACT

The general approach within lean construction is to make the construction process, as it is normally undertaken on the construction site, leaner by reducing non-value-generating activities. This is usually done respecting the traditional division of work into trades.

However, inspired by the manufacturing industries, this approach might be challenged. Manufacturing industries very seldom keep up the division of work into trades. Instead the product is divided into subassemblies, often made of independent suppliers down the supply chain under individual design and manufacture contracts.

The paper presents a five year Danish experiment within the housing sector, making this approach within six completed schemes and three in progress comprising app. 350 apartments, mostly in terraced houses.

Even though cost reductions have been hard to demonstrate, a number of other benefits have been found. Increased focus on customer value, shorter project completion time, much fewer faults and omissions, and higher customer satisfaction.

The paper outlines the approach and reports on some of the lessons learnt and discusses the experiences in relation to the Lean Construction theories.

KEY WORDS

Lean production, integrated production, industrialization, modularization, complexity.

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INTRODUCTION

The division of work within the construction sector is most often made by trades. Indeed, even the design work is divided in this way between the architect and engineers of different kinds. This division of work is so natural that almost nobody challenges it. The work is mainly undertaken by skilled labor employed by their own kind of firms: the carpenters in their firm and the plumbers in their. The firms are thus highly specialized through the workers' skills, their tools and their materials. But not by their product.

ATV (1999) shows that this division of work leads to a design process separated from the manufacturing, few formal process definitions, uncertain borderlines, weak control of price/quality during the design process, and little feed back of experiences from the construction site to the design.

When comparing with modern, lean manufacturing, this peculiarity within construction becomes very clear. Almost all manufacturing industries are specialized through their product. Some very much so, and the production workflow takes place through a chain of suppliers, each providing their product or subassembly, often made under a separate design and manufacture contract.

This division of work makes it possible to integrate design and manufacture, to establish clear and firm process definitions, to establish well defined borderlines between the suppliers, to draw a clear picture of the value generated by the cost of each module, and to feed back experiences from the manufacturing and delivery processes directly into the design of the next product generation.

The paper introduces the integrated production principles and describes their use in the construction industry as tried in practice in Denmark. The experiment shows that the approach is indeed feasible, and through an in depth discussion the paper paves the road for others who might explore this route to a leaner building process.

INTEGRATED PRODUCTION

The term Integrated Production has been coined through a Danish nine-year development program: Integrated Manufacturing Systems, undertaken by researchers within manufacturing and product development at the technical universities in Copenhagen and Aalborg, Denmark, co-operating with a number of companies within the mechanical industry (Riis 1996).

The program objective was to reach a new and broader understanding of the integration between industrial enterprises, and to develop methods to utilize industrial co-operation. This can be seen as an implementation of the Lean Production principles in practice within leading Danish manufacturers.

EXPANSION ALONG THE CHAINS OF BUSINESS

It is of great importance within the manufacturing industry to maintain the capability of fast reaction to changes. Consequently, production can not be viewed as an independent activity, but must be perceived as a number of chains in which the production is one chain only. Other chains are materials flow and the product development process.

The flow of materials from the suppliers through the supply chains towards manufacturing, assembly, distribution, sale, delivery and commissioning must be integrated by means such as just-in-time logistics. This brings new tools based upon information technology into play, and new ways of collaboration are established, just as new models for the organization turn up, based upon mutual confidence and commercial integration. New roles for the participating firms and their employees and broader use of their competence come to the surface.

The product development processes change as well. Integrated design systems for retrieval and re-configuration of existing solutions combined with common systems for order processing and production planning, tie the parties in the supply chain close together. Integration is another consequence of looking upon the end products as product families with a diversification to suit the markets but based on modules. This approach reduces the complexity and supports repetition.

INTEGRATION

Fast response to market changes calls for integration within the company, removal of internal borderlines and local conflicts of interest, just as sub-optimizing must be avoided.

Integration along the materials supply chain may have lead-time, process time and costs as guiding parameters. The processes are – in a development perspective – the starting points for a continuous improvement, as well as a more innovative stepwise development. Integration calls for a new understanding of their role by the employees, and development of new competence based upon a broader understanding of the whole process. In some industries a new understanding of foreign languages and cultures may be part of this integration as well.

A special challenge is to establish the integrated learning, which step by step increases the employees' understanding of the integrated competence.

INTELLIGENT PRODUCTION

Usually the term Intelligent Production is interpreted as the use of information technology within the manufacturing processes. But the term can also be understood in the meaning maximum use of the human intelligence, creativity and imagination.

The use of information technology pulls towards an industrialization of engineering activities. In this, the manufacturing industry draws closer to the knowledge industry and will soon recognize that effective engineering may be the primary challenge for the engineer of the future. However, this industrialization does not necessarily bring us creativity and intelligence. The IT systems must remove the boring and unproductive mental processes, release new potentials, and – not least – support the organizational learning.

EMPLOYEE INVOLVEMENT

New challenges to the enterprise cannot be met without a new understanding of the role of the employees and their function. The employee must understand, identify himself with, and participate in the realization of the essential company goal of creating a prosperous co-operation with other organizations.

Core issues are engagement, motivation, development of competence and involvement in the day to day processes as well as in the ongoing renewal of the business. Decentralizing and mutual learning are of utmost importance.

THE *HABITAT* EXPERIMENT

The tradition of organizing the building process into trades was challenged by *Habitat* – one of the four consortia awarded the development contracts under a five year Danish program aiming at improving the product as well as the process within the building sector. (Erhvervsfremme Styrelsen 1995), (Bertelsen and Nielsen 1999).

Habitat was in its approach very much inspired by the Integrated Production principles, which were 'translated' to suit the building process, and most of the proposed ideas were later tested over the six projects completed and the three in progress. The *Habitat* experiment is reported in detail – but in Danish – by Bertelsen (2000) and summarized in (Bertelsen et al 1999). ATV (1999) reports the distinction between the traditional, process-oriented organization of the building process and the new, product-oriented strategy based on an discussion which has taken place within the construction industry in Denmark over the recent years.

THE *HABITAT* STRATEGY

The *Habitat* approach was to divide the construction work into subassemblies in the form of modules, which again were divided into systems and components, instead of dividing it into trades. By this approach, detailed design, manufacture and erect contracts were made possible, and it was envisaged that this would make it easier to feed back experiences from the construction site into design and manufacturing as well as to utilize the manufacturers' knowledge to a greater extent.

It was also thought that this approach would make it possible to develop a new project design process with an intensified dialogue between the designers and the client putting more focus on the generation of value, but with a firm cost control as well. This 'Lean Design Process' was planned to take place through a series of whole day workshops. The use of 3D Computer models as a workshop tool to demonstrate the final result at an early date was planned as well.

Finally flow management based on principles from the Danish development project: *Byggelogistik* (*Building Logistics*) was to be included. *Byggelogistik* was an experiment, which in the early 90'ties demonstrated substantial efficiency gains by using methods similar to the Lean Construction Methods: Last Planner and Look Ahead Plan, but for the management of the materials flow mainly. (Bertelsen and Nielsen 1997)

DIVISION INTO SUBASSEMBLIES

It was found that such an approach was indeed feasible. And more important, it was found that a number of skilled manufacturers already existed within the building industry. They had already most of the products needed and all the skills. What they lacked was mainly the incentive to move ahead and the opportunity to become major players in a product-structured building process. Their skills were indeed much higher than any of the *Habitat* management group had hoped to find.

Basically the building was divided into three subsystems: the groundwork and mains, prefabricated bathrooms, and walls and roofs in the form of prefabricated panels. As the modularization strategy is a central issue in integrated production and was so in the *Habitat* approach as well, the chosen strategy and alternative strategies are discussed in more detail in a later section.

THE WORKSHOP DESIGN PROCESS

The workshop design process was tried out very early in the program. But it was found that this approach requires participation of manufacturers who really know their product and their process. Otherwise the dialogue with the client is hampered by uncertainty around the costs of different alternatives.

Later, when system suppliers knowing their product and process were identified and brought into play as part of the team, the workshop worked remarkably well. Particularly, high customer satisfaction has been observed.

The design workshops used 3D computer models with great success to show the exterior and interior of the proposed building project. Indeed, a common virtual walk-through with the client, the users, the architect and the supply team before signing the final detailed design and build contracts has been tried, making all participants fully aware of the planned outcome.

FLOW MANAGEMENT

The materials flow management methods from *Byggelogistik* were successfully used in the first projects. But as the division into subassemblies and systems became more organized, it was expected that the need for a common materials flow management was lesser, as each manufacturer managed his own supply chain, and as each manufacturer had his own simplified flow of modules and materials onto the construction site. What was not recognized was that *Byggelogistik* basically is the Last Planner methods implemented through the back door. In managing the materials flow on a just in time basis, one has to plan the activities day by day and prepare look ahead plans as warnings to the suppliers.

In the later projects this fact has been recognized – together with the growing understanding in Denmark of the Lean Construction theory and methods – and a lean flow management is again introduced into the site process control.

EXPERIENCES

The first experience with the building system was, as mentioned, that it works. Even though the first construction jobs were undertaken without the foreseen prototyping, the system in general worked very well. Due to the form of co-operation within the *Habitat* consortium, two different sets of panel manufacturers were selected for the first two projects, which also were managed by different groups and executed under different types of contract. One was a *Habitat* contract proper, the other a turnkey form of contract. In both cases the projects were completed to the client's satisfaction and in the turnkey case with construction cost under the budget. Also in both cases the projects were completed to schedule, and a substantial reduction in the project delivery time, and in the site construction time particularly, was observed.

Later customer satisfaction surveys showed in general a great satisfaction with the product as well as with the delivery process by the *Habitat* contract, but not by the turnkey contract.

However, this is not the whole story. During the first projects a number of mistakes were made and a great deal of experience gained. There is no such thing as a free meal, and a modularized building process definitely has its own rules that must be strictly adhered to. One such rule is the need for higher accuracy, which will be dealt with in the following section. The experiences are dealt with in detail in (Bertelsen 2000).

DISCUSSION

RELATION TO THE LEAN PRODUCTION PRINCIPLES

Wormack and Jones (1996) identifies five principles which should be focussed upon in lean thinking:

- Identify product value

- Optimize the value steam
- Make the product flow
- Use pull logistics
- Pursue perfection

Habitat's process takes hand of the value generation through the work shop design process. It takes hand of the value stream optimization through the integrated design, manufacture and erect contracts with module suppliers and in turn through these manufacturers' co-operation with their sub-suppliers. The product flow is adhered to through the order specific design and manufacturing process and through the shorter construction time obtained through the parallel detailed design and manufacturing processes. Pull logistics is introduced through the introduction of the last planner methods on the construction site and through the manufacturers' own logistics in their dealing with their sub-suppliers. Finally, the optimization is managed by the continuous feed back from the construction site to the modules manufacturers' design offices, through frequent time outs with participation of all suppliers, the design architect and *Habitat*, and through customer satisfaction analyzes.

DEGREE OF IMPLEMENTATION

Koskela (2000) analyses 8 cases in relation to the implementations of principles and methods based on different concepts of production.

Using this approach on the *Habitat* experiment shows: *Transformation* was implemented through the use of industrialized processes in the manufacturing of the modules. *Flow* was implemented through the logistics for the materials procurement, the use of last planner and the shared project information on a common web site. *Value* was implemented through the workshop design process, the increased customer focus and through the customers' satisfaction analyses.

Koskela analyses the level of implementation as well. As for *Habitat* the principles were implemented on the *design* level through the process design, the modularization strategy, the integrated project database, and the use of standardized detailed solutions. On the *control* level the principles were implemented through JIT logistics, and last planner flow management. On the *Improvement* level implementation took place through systematic feed back from construction site to design office, frequent time outs with participation of all manufacturers and designers, and joint improvement projects with focus on new solutions; for instance, the heating system.

The *Habitat* experiment thus implemented the new principles comprehensively, on all levels of management and in accordance with all three views of production – as is theoretically recommendable.

LENGTH OF FLOW

Koskela (2000) points out that in industrialized construction the flow is longer, due to multiple production locations, the amount of design required is larger, the error correction cycle is longer, and requirements for dimensional accuracy are higher than in site construction. To this we can agree in principle, but the question in practice is not the length of the flow but whether it is more cost effective and easier to control.

The flow is indeed longer, but easier to manage as well, because the large amount of different building materials is delivered in well-organized flows to permanent fabrication facilities, from where a relatively few modules only are shipped to the building site. The need for detailed design is certainly larger, but most of this detailed design is standardized solutions already sitting in the manufacturers CAD system. Certain error correction cycles may be longer, but most are definitely shorter. As most of the detailed design is encapsulated in the modules, the manufacturer corrects his mistakes as soon as they are found. And by encapsulating the 'right' solution in his design system, errors are hardly ever repeated. Industrial learning becomes an integrated part of the game.

As for the accuracy it must certainly be higher, but so it is in manufacturing. The challenge is to co-ordinate the tolerances. Usually the *Habitat* module suppliers deliver their product to a construction site, where trade contractors take care of the neighboring building parts. This makes interface management easy. If a small deviation occurs in the module, the trade will probably never observe it, and will take care of it by means of a plane, caulking or other craft methods. By a complete modularization this opportunity for correction is no longer available. Now the module will face another module, and the two have to fit exactly. The worker with the plane or caulk pistol is no longer there.

Thus, at the same time as the modularization encapsulates a number of management tasks within the module, a much stronger emphasis must be put on the management of the interface between the modules. One reason for this has already been touched upon, namely the great importance of the modules fitting correctly together. Another reason is that once it is recognized on the site that the interfaces are not in order, a great number of modules are already finished or are so far in the production, that changes are next to impossible to make.

COMPLEXITY

Howell and Koskela (2000) consider the construction process as a complex phenomenon. They point out that the complexity is not considered in the traditional project management practice and that the higher complexity might be the reason for the frequent failures. And Koskela (2000) concludes his considerations concerning industrialization: *Thus, the total process of industrial construction tends to become more complex and vulnerable in comparison to site construction*.

The issue of complexity may be a very important point in the understanding of the construction process. The complexity of project organized ventures stem not only from the project itself, but also from the tie-in with other, ongoing projects in which the project participants may be involved at the same time. Indeed, from this point of view the entire construction industry can be looked upon as one integrated and very complex system.

This point of view gives rise to the question whether the *Habitat*-approach makes the process more or less complex than usual and – more important – whether it makes it more or less easy to manage.

There have not been made any formal analyses of the complexity of a *Habitat* project, or of any other project that the author knows of. And which definition of the term complexity should be used for such an analysis? Probably it is not the complexity in a mathematical sense that matters but the system's predictability in the time perspective required for the establishing continuos work flow?

Based upon this definition of the term complexity it is the participants' feeling that the end product is more complex because of the higher number of industrialized modules, systems and components. For the same reason the process as whole, i.e. as the sum of all the activities might be expected to be more complex, but this is not the case. The clear division of responsibilities and the encapsulation of the design within the modules makes the process much more ordered. And it is indeed much easier to manage the *Habitat* process because of the more logical distribution of tasks and responsibilities and because of the very simple interfaces between the modules. The designing architects concentrate on the over-all design and leave the details to be solved by people, who have the production experience. The responsibility is thus made very much like product responsibility.

Also, the clear division into functional modules and systems makes the process as a whole more robust and the simplification of the on-site work makes establishing and managing buffers easier.

Greg Howell expressed in his presentation of Howell and Koskela (2000), that nature's answer to higher complexity is to increase the local competence and to delegate responsibility. In this, the *Habitat* process seems indeed in better accordance with nature than the traditional one.

BUILDING MODULARIZATION STRATEGY

As the division of the constructed artifact into modules is a corner stone in the *Habitat* approach, the strategy for this division is clearly of great importance. This strategy is therefore dealt with in greater detail in the following.

Initial Approach

The initial approach to the modularization was to keep it as simple as possible and at the same time utilize already existing production capabilities on the Danish market. Prefabricated bathrooms have been a product in the marketplace since the mid 50'ties, even though their use in Denmark has been limited in recent years.

The fabrication of modules for the roof and for external and internal walls is an established industry as well. As the production normally is undertaken by the same kind of firms, it was decided to contract for all the panels in one package. As a supplier of the heating and ventilation systems as modules was not found, it was decided to make those parts of the building as traditional crafts, and contract them as a part of the panel package. The building base and the external works were initially considered a traditional civil engineering contract, and contracted as such under a design and build arrangement. This strategy can with reason be named: Modularization in accordance with production capabilities.

However, it was soon recognized that even though this strategy was the easiest, it was probably not the best. Other considerations were to be made.

Modularization by the Need for Development

It became soon evident that whereas the panel manufacturer was highly skilled in this type of product, he was also focused on this part of the system only. His interest was lost when it came to the interior completion in general and to the piping system for heating in particular.

At the same time it was recognized that the heating system was the cause of a high number of traditional craft operations to be undertaken after the building envelope was finished. This was partly because of the Danish tradition for a) using heating systems based on hot water lead to radiators, b) hanging the radiators on the walls under the windows and c) installing the pipes beneath the floorboards. As the heating system was not redesigned to be prefabricated, the installation of piping made a prefabrication of the floors impossible, and further made it necessary to make the wall papering and interior painting a trade contract as well.

To overcome this, it was recognized that the heating system should be made a separate module, making it possible to develop a completely new system, suitable for manufacture and fast installation. This should probably be in the form of a central, 'intelligent' unit heating the rooms by hot air and at the same time undertaking the ventilation and heat recovery.

Further examination will probably reveal that other parts of the building should also be isolated, making them suitable for further product development. The electrical systems are definitely one such part. Such a strategy can be named modularization by the need for development.

Modularization by Value

Another alternative strategy that looks promising is modularization by value generation. The kitchen is – besides the bathrooms – probably the most important single component in the value stream, once location and size have been decided.

The kitchen fitting out is a fairly simple operation normally undertaken by the firm that manufactures the cupboards. Also in terms of costs it is a fairly small contract as the kitchen cupboards and appliances accounts for app. 3% only of the total construction cost in the normal Danish housing schemes.

Bringing the kitchen into focus by isolating this part as a separate module is therefore because of its value generating capability. The panel module contractor tends to neglect this part of his contract, being as simple and small as it is. But from the *Habitat* point of view this is definitely not the case. A close co-operation with the kitchen manufacturer is expected to bring a substantial increase in value at little extra costs.

Also the encapsulation of the heating and electrical systems are expected to put focus on their value generating capabilities.

PROJECT PARTICIPANTS

The *Habitat* consortium was formed in accordance with the requirements in the development program. It was mandatory that it at least comprised a housing association, an architect, an engineer and a general contractor. In the case of *Habitat* two architects and two engineers participated along with three materials suppliers and an electrical and mechanical contractor, making the number of participants ten.

The consortium was formed before the development of the modularization approach, and as it turned out, none of the participating firms were capable of delivering the modules. It was soon agreed that the participating firms in general should act as owners of *Habitat* and that *Habitat* should operate on its own, trying to establish itself in the market in its own right. But as the *Habitat* approach to the building process is completely new, *Habitat* was more and more seen as a competitor to the owners' own operation. The contractors saw that most of the construction work went to the manufacturers. A great part of the design work was included in the module contracts reducing the architect's and engineers' fees, and the suppliers saw that their deliveries of materials came under a stronger pressure than usual because of the manufacturers' professional materials purchase. The only truly satisfied participant was the housing association.

However, the organization worked fairly successfully as long as the development efforts, which were partly financed by the government, took place. *Habitat* was therefore foreseen to continue its operations after the end of the program, but here the need for additional capital came into focus. And now the competitor views became clear. None of the owners wanted to provide the extra funding and it has not as yet been possible to find an external source for this funding. It has therefore been decided that the owners will utilize as much or as little of the ideas within their own operations and to close down the *Habitat* itself.

The problem may be Danish only. But it seems hard to attract venture capital to the building industry besides from the firms already operating within the sector. And all of these have their own core business to defend.

Who is to be the much needed change agent in this very conservative sector?

CONCLUSION

The main conclusion of the *Habitat* experiment is that lean production of individual buildings within the multifamily housing sector is indeed feasible. A number of advantages can be obtained, and even though the expected cost savings have not been clearly demonstrated in practice, it is the expectation by the participants that this would be the case, if a longer sequence of projects and a steadier order flow had been established.

It can also be concluded that even though the complexity is higher, the task of project management is much easier, making it possible for the management to put emphasis on the value generating processes.

Finally it can be concluded that the approach gives rise to a much more efficient learning process than the traditional division of work within the building sector.

REFERENCES

ATV (1999). *Byggeriet i det 21. århundrede – industriel reorganisering af byggeprocessen*. ('The Building Industry in the 21st Century – Industrialized Re-organization of the Building Process', In Danish with an English summary). Akademiet for de Tekniske Videnskaber.

Ballard, Glenn (2000). *The Last Planner System of Production Control.,* School of Civil Engineering, Faculcy of Engineering, The University of Birmingham.

Bertelsen, S (1999). *Faglig Slutrapport, Habitat's Udvikling under PPB-programmet* ('The *Habitat* development under the PPB-program', in Danish). Not published, but available on www.*Habitat*-byg.dk

Bertelsen, S. (2000). *Lessons Learned Form the Habitat Development.* Not published, available from the author.

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

Bertelsen, S. and Nielsen, J (1999). *The Danish Experience from 10 Years of Productivity Development*. 2nd International Conference on Construction Industry Development and 1st Conference of CIB TG 29 on Construction in Developing Countries.

Bertelsen, S; Myrup Andreassen, M and Thomassen M.A (1999). *Integrated Production Applied to the Building Process.* Not published, available form the author.

Erhvervsfremme Styrelsen (1995). *Process and product development in the building industry – a Danish development programme.* Danish Agency for Industry Development.

Howell, G. and Koskela, L. (2000). *Reforming Project Management: The Role of Lean Construction.* IGLC-8, Brighton 2000.

Koskela, L. (2000). *An exploration towards a production theory and its application to construction.* VVT Technical Research Center of Finland.

Riis, J.O. et al (1996). *Det udvidede produktionsbegreb – Løsningsmodeller, udfordringer og perspektiver*, ('Extended Production – Models for Solution, Challenges and Perspectives', in Danish). Industriens forlag, København.

Womack, J. and Jones, D. (1996). *Lean Thinking.* Simon and Shuster.