LEAN CONSTRUCTION: WHERE ARE WE AND HOW TO PROCEED?

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Abstract

This paper is written in the light of the papers for the 12th annual conference in the International Group for Lean Construction. It tries to establish a brief overview of the development over the past twelve years and to establish the state of the art. From this its primary objective is to open a discussion of the future effort within the Lean Construction environment. The paper proposes that a change in the underlying paradigm is happening and that a new research agenda should be established with an outset in the lean understanding of the construction process as it is known from the construction sites and with a complex systems understanding of the nature of this process. Elements in this agenda are outlined and areas for research identified within the areas of maximizing value for the client, minimizing waste in delivering this value, and managing the project delivery.

Key Words: Lean Construction, complexity, management, value, waste

Introduction

This paper has been written while reading the papers presented for the 12th annual conference in the International Group for Lean Construction, which was held in Elsinore, Denmark, 3-5 August 2004. Its basis is therefore the papers presented for this and for previous IGLC conferences mainly. By this the paper tries to establish a state of the art within Lean Construction, even though it is probably biased towards the Danish implementation of the lean principles.

It sets out to reach a deeper understanding of the nature of construction. It does so from a firm belief that construction is a special kind of production in its own right and that this kind of production is of great importance for the build environment. Not all production generating buildings is construction, and these days we see more and more of the output from such productions as part of our environment. This change in construction from offering a process to delivering a product is discussed in the terms of two strategies for the development of the construction process. Next the nature of the construction process as a craft based production is discussed from a complexity perspective and the paper proceeds to propose a 'construction physics' as an understanding of construction as a production in its own right. Finally some aspects of a new understanding of construction management in the light of projects' complexity are discussed.

The objective of the paper is not to open a discussion on architecture or on the build environment in general within the Lean Construction society, but to investigate the properties where construction distinguishes itself from manufacturing and to identify some areas for future research of importance to help keeping the – compared to

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manufacturing – less efficient construction process alive as an instrument in generating works of art.

Setting the New Agenda

Improving the productivity in construction is a great challenge facing the construction industry. In many countries the growth in its productivity is much lower than in manufacturing – if there is any growth at all – and as construction in most countries accounts for app 10 percent of GNP – or in Denmark for as much as 25 percent of all production in terms of employees – this is not an acceptable situation for any national economy (Byggepolitisk Task Force, 2000). In an age of efficient manufacturing, construction is therefore very much in focus as an industry where performance improvement – even at a small scale – may have significant impact on the national economy. An Australian analysis of the impact of a ten percent productivity improvement in various service sectors showed that construction had by far the most impact at 2.8 percent on the gross national product and further 1.2 percent if Domestic Housing was included (Stoeckel and Quirke, 1992).

More specifically the demand for improvement in construction is to provide higher quality in the output and reducing the costs, offer a better process to the client, and increase working conditions and safety (Latham, 1994; Eagan, 1998; Byggepolitisk Task Force, 2000).

To a growing group within the industry Lean Construction seems to be the best way so far in reaching these goals.

The Nature of the Construction Industry

A Danish study (Erhvervsfremme Styrelsen, 1993) divided the construction sector into two parts: The *Construction part* and the *Industry part*. It did so recognizing that a development of the construction industry productivity as a whole would be difficult as it would call for different means. Development of the Industry part was supposed to take place through market mechanisms and if the productivity had to be improved further, a more efficient market for the products in the Construction part should be established. On the other hand, a development of the Construction part would call for a number of public initiatives, which gave rise to a series of development programs, which again have made the Danish construction industry aware of Lean Principles, Value Management, and cooperation and learning as the basis for a new kind of construction management.

Lean Construction: A Brief History

Lean Construction is to a great extent an adaptation and implementation of the Japanese manufacturing principles within the construction process and in doing this Lean Construction assumes that construction is a kind of production albeit a special one.

Even though the guiding principles were not formulated until after nearly ten years of work by Koskela (2000) and formulated in more detail in 2001 by Ballard et al (2001), one may easily deduce that from the beginning they were: *While delivering the project, maximize the value for the client and minimize the waste*.

Koskela (1992 and 2000) proposed – based on the development of manufacturing theories over more than a hundred years – the Transformation-Flow-Value (T-F-V) understanding of construction. Koskela and Howell (2002) suggested that the flow aspect should be given more attention in construction management in lieu of the current overemphasis on the transformation aspect.

The production theory for construction proposed by Koskela and not least the concept of production as a flow showed almost immediately its usefulness by practitioners rethinking the construction management methods (Ballard 1993, 1994, 1997 and 2000) and later the management principles (Koskela and Howell, 2002; Bertelsen and Koskela, 2002). Ballard's groundbreaking work on the Last Planner System[2] method has showed an efficient way of understanding and not least managing the flow aspect of the construction process and to many within the industry Last Planner is synonym for Lean Construction – which it is not of course.

The concept of flow management was taken even further by using the methods introduced by Jim Womack and further developed by the Lean Enterprise Institute (Womack and Jonès, 1996; Rother and Shook, 1999). Not least the work undertaken at Berkeley by Iris Tommelein and Glenn Ballard (Holzemer et al, 2001, Ballard et al 2002, Elfving et al 2002, 2003 and 2004, de Alves et al 2004), has given a useful understanding of the room for improvement within the more ordered part of the construction process – the industry part – mainly, but also in the use of buffers and in the interplay between the ordered world of components manufacturing and the complex world of the construction process.

Around the same time that Koskela proposed the manufacturing-inspired T-F-V theory, voices were raised that the construction process might be even more complex and that it should be understood in a completely new perspective as well. Gidado (1996) presented a study of project complexity and suggested a numeric method for analyzing the complexity. Radosavljevic and Horner (2002) discuss evidence of complex variability in construction in which they found analogies to the pattern found in complex, dynamic – or chaotic – systems, and Howell and Koskela (2000) led a similar discussion at the 8th annual conference International Group for Lean Construction albeit without much attention from the audience. Inspired by this discussion, Bertelsen (2002) reiterated the idea that construction must be understood as a complex and dynamic system and later presented a broader study of its complexity (Bertelsen 2003a and b).

Koskela and Howell (2002) suggested that construction management as - one of several understandings – is understood as a scientific experiment. By this they accepted the unpredictable nature of the construction project, which indeed is a general characteristic of any complex system. But this acceptance of construction as a complex and dynamic system has much deeper implications for the future development of the Lean Construction principles as it challenges the underlying production theory, which is inspired by the ordered and foreseeable world of manufacturing mainly.

The challenge stems from the difference between the two types of systems – or rather from the two states as the terms: ordered and chaotic[3] expresses. In a mainly ordered system order can be increased by reducing variability and disorder controlled with for

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[2] Last Planner System™ is a trademark of Lean Construction Institute

[3] In this paper the term chaotic is used in the mathematical/physical meaning: "deterministic unpredictable" that is that small differences in the outset do not stay small after a limited number of steps.

instance diligent use of buffers, well defined processes and procedures, and elimination of sources for errors. Chaotic systems on the other hand must be managed based on principles such as cooperation, conversations and learning (Macomber and Howell, 2003 and 2004; Elsborg et al, 2004).

The concept of creating value has – to the extent it has been dealt with at all – focused at value engineering mainly, that is methods to ensure that the value specified will be delivered to the client while the cost is kept as low as possible, a principle which in its nature deals with minimizing the waste.

However, the 12th conference in 2004 opened the discussion of the value creation process in its own right by contributions by Stephen Emmitt (Emmit et al, 2004) based on a model for the value creation process described in a Danish guideline: The Client as Change Agent (Bertelsen et al, 2002).

Looking over the issues dealt with in the first dozen years of the history of Lean Construction one may claim that by far most of the work has been dealing with the reduction of waste, a little work has been looking at the project management principles and even less has addressed the issue of maximizing the value for the client.

Towards a New Agenda

The state of the art as presented above seems to indicate that Lean Construction is moving towards a new agenda. Even though there is still much to be learned about how to minimize waste and manage buffers, the area of value generation calls for much more attention, as does the project management principles.

In turning the focus to these two areas the underlying understanding of the construction process will inevitably change from the simple one to the complex model. The client represents a complex and dynamic system[4], the production system is complex due to the sharing of – and competing for – resources with other projects, just as the process itself is complex and dynamic due to its one-of-a-kind nature. (Bertelsen, 2003b)

As a consequence, Abdelhamid (2004) suggests based upon Boyd (1976) that the underlying paradigm of the construction process is undergoing a shift. From a pure transformation view it is moving through the Transformation-Flow-Value view (Koskela, 2000) and into the understanding of construction as a complex and dynamic system, where cooperation and learning become the guiding metaphors (Bertelsen, 2003a).

This new understanding of construction as a complex and dynamic system leads to a rethinking of several of the principles guiding the development of Lean Construction. Bertelsen and Koskela (2004) suggest some routes towards new principles for construction management just as the work of Emmitt et al (2004) seems to indicate routes worth exploring in the issue of value generation.

These issues and some topics for further studies are discussed in the following sections. The discussion begins with two strategies for meeting the challenges for improved productivity facing construction these days. The two strategies are discussed with consideration of the construction process as a complex production system.

[4] This is an issue not dealt with specifically within Lean Construction even though Bertelsen et al. (2002) proposes a model for understanding the client from a value generation perspective.

Two Strategies for Construction Improvement

In meeting the challenge construction faces there seems to be two different strategies: to reduce the complexity to a level where the principles from the ordered world of manufacturing can be used as they are, or to develop new methods for the management and control of the construction process as a complex system, or – as it has been stated in Denmark – either to develop the product or the process (Byggepolitisk Task Force, 2000; By & Boligministeriet, 2001). In practice the product strategy means to transfer more and more parts of the construction work into off-site fabrication – and thereby make the site work an assembly only, whereas the process strategy aims to develop the on-site construction process in its own right.

These two strategies are dealt with in more detail in the following.

Making Construction – a kind of – Manufacturing

This strategy is based on recognizing that not every production resulting in a building is construction. Some cases – f.i. prefabricated standardized metal buildings – are fabrication of a kind well known to the manufacturing industry (Akel et al, 2004). But also the manufacturing of components, materials and systems becomes more and more developed. Structural steel and concrete slabs are almost always pre-fabricated, the envelope is often so as well, and recently we have seen approaches towards prefabricated HVAC-piping. (Holzemer et al, 2001; da Alves and Tommelein, 2003; Pasquire and Connolly, 2002, 2003) Also the construction materials turn more and more from being basic materials as timber, bricks and cement into being components or systems with a much higher degree of prefabrication, making the process at the construction site more and more an assembly process than actual work of craft, and industrial thinking about new issues such as the management of tolerances comes into focus (Milberg and Tommelein, 2003 and 2004; Björnfot, 2004).

This strategy becomes more and more common as can be seen from the steady growth of the supply industries and the development of their products into systems. Even though this strategy may seem to increase complexity as the products become more complex and the depth of the supply chain grows (Koskela and Vrijhoef, 2000), it is in its nature a reduction in the total project complexity. The project may still be a one-of-a-kind product, but as it is more and more composed of industrialized modules manufactured in ordered and controlled environments where manufacturing management principles can be applied, the complexity of the construction process is reduced substantially (Bertelsen, 2001). This experience is in complete accord with the outcome of modularization in manufacturing in general as shown by Baldwin and Clark (2000).

The product strategy has two branches: the open and the closed systems, the choice between which may be of great importance to the outcome of the development of the construction process. The open branch makes systems, which can be combined between different manufacturers giving a high degree of flexibility and making a large room for the architectural design. Closed systems – on the other hand – are proprietary and even though they may be designed with a great respect to variety, the benefits of mass production and the fierce competition on the market tend to make their output fairly uniform. The standard US manufactured home is one such outcome. If the product strategy gains too fast influence in construction, one may fear that also the open systems will gradually grow less and less open as there will always be some parts of an open system that is more important for the manufacturer to support, than other. The increasing benefit of scale may therefore steer the development within this area towards more and more uniform products as it has done in many other types of consumer goods.

However, regardless of the branch, the manufacturing approach puts focus on modularization and thereby reduces the complexity substantially. In doing so it improves productivity as well as quality, and – as long as the openness is kept through efficient modularization – also the competition between systems with identical functionality (Baldwin and Clarc 2000, Bertelsen 2001, Björnfot and Stehn, 2004). Therefore the product strategy in general may solve several special needs, such as rapidly increasing the output, and bringing low cost building to a market in need. But anybody dealing in earnest with the term "Build Environment" should have concerns – at least towards the closed systems.

For the future of IGLC one may argue that the more construction turns into being off site fabrication the more Lean Construction will be similar to Lean Manufacturing. However, some may still want to look for improvements in the construction site process as we know it to day.

Developing Construction as a Process

In a recent Danish proposal for a research centre on project management in construction professor Kristian Kreiner has proposed that construction should not be understood as an industry but as a process (Kreiner, 2004). One may claim that the same goes for the client – he is not a person or even an organization, but a temporary, complex system providing requirements and decisions in an unpredictable flow.

Construction is the production of unique products of art on a very large scale. Now, the problem in improving construction productivity is that very few seem to understand construction as a production in its own right. Koskela (1992, 2000) has – probably as the first – suggested a theory for construction as a production, a topic that has been dealt with in manufacturing for more than 150 years.[5]

Construction complexity stems from several sources. From the nature of the unique product and from the associated undocumented production process, from the temporary production system where resources are shared between projects by subcontractors working on several projects at the same time, and from the ad-hoc organization – not least the client's organization – which must be understood as a complex social system.

The dynamic stems also from the ever changing participants in the process over the project life cycle and not least from the fact that every project is somebody else's subproject[6] and thus subject to the overlaying project's dynamics. Indeed, complexity

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[5] At least in Denmark, but probably also in the UK as can be seen from the Eagan report, this understanding of construction as a process in its own right has not penetrated the thinking within government agencies, which lays down the framework for the industry and establishes programs for the development of the industry. Indeed, the impact of this lack of understanding should be a research issue in its own right.

[6] A quotation from: *A long term view of project management – its past and its likely future* by Dr Martin Barnes, Cornbrash House, Kirtlington, Oxfordshire, UK, made at the 16th World Congress on Project Management – Berlin, Wednesday 5th June 2002.

http://www.pmforum.org/library/papers/MARTIN%20BARNES%20Berlin%20June%202002%20revised%20post%20conference.htm, Last visited September, 2004.

is abundant in construction everywhere you look. In an ever faster changing world the dream of the stodgy, ordered project is just a dream.

In other words: Construction is the undocumented process that takes place as an interplay between a complex and dynamic customer, and a complex and dynamic production system at a temporary production facility.

The introduction of the complex system understanding of construction challenges construction research. Studies must spread out from the traditional disciplines and into the understanding of such strange areas as networks, emergence, self organization, learning, and chaos, and further into understanding construction in the light of these new disciplines. In keeping construction basically as a production process in its own right the challenge will be to improve productivity at a rate that makes competition with prefabricated systems possible.

Lean Construction has directed attention and focus to some very important ways of doing so. The challenge is not to improve the productivity in undertaking the transformations – which takes a mere 30 percent of the working time (Hammerlund and Rydén 1989, Nielsen and Kristensen, 2001) and therefore counts for ten percent of total construction costs only – but to improve the flow and to put focus on the value generation. Improving flow may not only reduce the time wasted on waiting and used on transport, but it may also reduce the cost of the building materials themselves, which in Denmark counts for around two thirds of the total construction costs. Studies in nearby Sweden show that one third of the cost of building materials is not associated with the materials themselves but with packaging, storing, handling, transport, and getting rid of package and wasted materials (Bertelsen, 1993 and 1994). Experiments also demonstrate that substantial improvements in the flow of materials are obtainable with simple methods, which ties nicely into the use of Last Planner (Bertelsen and Nielsen 1997, Arbulu et al, 2003, Arbulu and Ballard, 2004). Improving the flow of information may open for similar improvements of productivity and reduction of waste.

But the options for improvement do not stop here. Management by conversations as proposed by Macomber and Howell (2003) will open for complete new ways of improving the construction process. An example of this is the use of PPC as poka yoke instrument, presently being tested in Denmark. This use of PPC suggests that the completion of a task should not be judged by the crew undertaking the task but by the crew taking over the result, and that one criterion for completion is a correct outcome. In doing so, the Shingo principle of single piece flow as a means of quality control is introduced in the construction process (Misfeldt and Bonke, 2004).

Indeed, there seems to be great room for the improvement of the construction process by implementing new management ideas, based upon a deeper understanding of the nature of the construction process – a construction physics – which is the topic discussed in the following sections.

Establishing Construction Physics

Factory Physics

Factory physics is based on the understanding of production as an ordered system, which is similar to the industry part of the construction industry, but very different from the construction part. The use of the 'factory physics' principles seems to repeatedly enter the discussion on Lean Construction. The term was adopted from

Hopp and Spearman (1996) and was introduced by Koskela (2000) and taken up in more detail by Ballard (Ballard et al, 2002). Several authors have since then discussed the term and the principles it entails.

Much inspiration and understanding can indeed be gained from these principles but there is a danger in over-extending them to construction. Factory physics is based on the understanding of production as an ordered system, which is similar to the industry part of the industry, but very different from the construction part. This is also one of the reasons why advocates of Lean Construction are increasingly separating Lean Construction from Lean Production by challenging the underlying theories and by questioning the value of the lean methods as introduced by the Lean Enterprise Institute (Womack and Jones 1996, Rother and Shook, 1999) for construction (Bertelsen and Koskela, 2004). Indeed, even the direct use without a deep re-interpretation of the ideas of the long standing Japanese manufacturing gurus: Shigeo Shingo and Taiichi Ohno may be challenged in construction.

Instead of following the ordered world of manufacturing and its principles, the challenge to the construction industry is to establish its own 'Construction Physics'. The general principles for a 'construction physics' should be the same as proposed by Koskela (2000) and presented in detail by Ballard et al (2001), namely to maximize value and minimize waste.

Maximizing Value and Minimizing Waste

But the new understanding of construction as discussed above has severe impact on almost all aspects of the understanding of the construction process as outlined in this section. The subsection headings in the following parts of the paper were originally taken from the IGLC championships but in doing so, the author himself made the serious mistake of believing that the understanding of construction as a complex system can be divided into smaller problems, which can be dealt with independently. Any complex system must be seen as a whole because 'more is different'[7].

However, even in dealing with the whole a structured approach is needed. In this section, different points of view on the construction process are chosen instead of different disciplines as depicted in much research.[8]

The approach used here is firstly to understand construction as a complex production yielding value to the customer – the objective of construction. Recently the lean principles as put forward as means to improve the manufacturing process by Womack et al (1990 and 1996) have been challenged as a theoretical basis for Lean Construction, but the Japanese understanding of construction is still very much in focus (Bertelsen and Koskela, 2004). One central aspect in this understanding is the principle of minimizing waste. Therefore the issue of waste in complex systems is dealt with next, before the focus is turned towards the understanding of construction as a flow inspired by the work of Koskela (1992 and 2000) and buffers – the interface to the ordered world of production of materials and components – is briefly considered. Finally some ideas on future project management are discussed.

[7] The title of the reputed paper on complexity by Phillip Anderson, (Science 19, 177, 393-396; 1972)

[8] This may be seen as another challenge in understanding construction from a complex perspective – how to organize and structure our studies?

Maximize Value

Construction as Conceptualisation of Value

In general, the work within Lean Construction has its weakest point in understanding, dealing with and managing value, which is a topic of growing importance as projects become more complex, dynamic and fast. Some authors have over the years made an approach to this theme, but mostly with an outset in methods found in value engineering or similar disciplines. Barshan et al (2004) offer an interesting analysis of the perception of value in manufacturing and claim, supported by experts such as Dr. Deming, that the customer has no influence at all on the value specification of a new product, whereas the customer plays a very important role in the specification of value in construction.[9]

Wandahl proposes a Value Based Management approach inspired by modern management principles (Wandahl 2003, Wandahl and Beider 2004). In this approach, the value for the customer is considered as product value and the value for the workers and project participants is termed process value.[10] However, this author proposes that lean construction reserves the term 'value' to express value for the customer only. Value for the project participants must be seen as a part of the labor relations, which Elsborg et al (2004) show can be of great importance in improving the construction process.

The Nature of the Client

When seeing construction as generation of value for the client, the first challenge is to come to grips with the nature of the client. The term 'client' indicates a person or a specific group of persons with a clear perception of their value parameters. Indeed, quite a few processes in construction are formulated along this line of thinking. Take the general rules for architectural competitions as an example. They have as an outset the understanding that the client requirements can be stated in a program that can be interpreted and acted solely upon by the competing architects. But as shown by Green (1996) this is not the case. The dialogue between the client and professionals must be understood as a learning process, where the parties through a series of conversations reach a mutual understanding of the needs and the options. But in this, Green still assumes that the client is a fairly well defined group of people that can be represented at the value sessions. In the real world, however, this is often not the case. Because of the nature of construction and of the constructed artifacts, the true client in the construction process is an intangible and undefined identity.

Construction is often creation of unique works. Whereas manufacturing identifies the market's value parameters and develop the product accordingly, construction integrates the product development with the actual production. Also construction does not have one specific customer but delivers products which are of importance for many. The client is the representative of a number of interests in different time

[9] "The customer invents nothing. The customer does not contribute to design of product or the design of the service. He takes what he gets. Customer expectations? Nonsense. No customer ever asked for the electric light, the pneumatic tire, the VCR, or the CD. All customer expectations are only what you and your competitor have led him to expect. He knows nothing else." (Stevens 1994).

[10] The term process value is used by Emmitt et al (2004) and Bertelsen et al (2002) for the customer value related to the project delivery.

perspectives. This will inevitably lead to dealing with conflicts, which again must be dealt with through discussion of alternatives. Simple tools such as Value Engineering and Quality Function Deployment loose their usefulness, and much more complex concepts such as value management, workshops, learning and adopting must be brought into use to support the process (Green, 1996). This brings forward another challenge: how to keep costs under control – or how to design to budget – in such a complex and dynamic one-of-a-kind process?

Bertelsen et al (2002) proposes a nine-dimensional understanding of the client. The client represents the owner, the users and the rest of the community, which have to live with the building as part of their city, square or street, and the client has to do so in three time perspectives: while it is designed and erected, when the building is completed and in use, and far into the future. Indeed a complex system, probably just as complex as construction itself.

This situation becomes more complicated as one recognizes that the design process is very rich in wicked problems, which are problems without an optimal solution (Lane and Woodman, 2000). The solving of such problems must be based on dialogue and learning reaching a compromise, but how to do this with an intangible client?

A Value Focused Building Process Model

Green (1996) also offers some ideas on value management, which put focus on the initial project stages where the value parameters are specified. These ideas have been further developed in the ongoing work in Denmark (Emmitt et al, 2004), and Bertelsen et al (2002) suggest the 'The Seven Cs phase model' for this process.[11]

The premise of this work is to understand the construction process as consisting of two distinct processes: Value creation and value delivering. These two processes are named <u>C</u>oncept and <u>C</u>onstruction and are most often separated by a <u>C</u>ontracting phase. Before the start, the client should formulate the requirements for the project through a <u>C</u>lient's brief and make a <u>C</u>ontact to the professionals with whom he/she wants to execute the project. The client has a set of requirements and a budget limit and in the concept phase the challenge is therefore to maximize the value within this financial constraint. Stuart Green coins this *Value Management* and sees it as a learning process between the client and the professionals. The construction phase, on the other hand, is a phase of production and here the goal is to minimize waste in order to deliver the value agreed upon as efficiently as possible. Methods used here are similar to those found in *Value Engineering* and in lean manufacturing and construction for the product and process parts, respectively. In this thinking it is emphasized that focus should also be placed on the concept of value associated with the process along with the product value.

However, much work remains within the area of value and value management including how to maintain and communicate the projects' specific value parameters during the whole project life cycle. Lund (2004) opens this discussion albeit for a short but important span within the project life cycle only.

[11] In this, the actual work is divided into three main phases: Client's brief, Concept and Construction. At the end of each of these phases comes an action: After client's brief follows Contact; after concept follows Contract; and after construction follows Commissioning. Finally the whole process receives a feed back from the client's Consumption.

Integration of Design, Engineering and Production

Complicated as the design phase itself may be, it becomes even more so because of its dynamics. “Every project is somebody else’s subproject” as Dr Martin Barnes stated. Almost any construction project will be met by requirements of fast completion in a dynamic setting where frequent changes are not the exception but the rule. Simultaneous engineering and construction may in the future be the general situation rather than an exception. An efficient lean construction process offered to the client may therefore carry quite an amount of value in its own right.

This leads the engineering process to a situation where alternatives must be developed and kept open over a long period of time, and methods such as British Airport Authorities’ idea of managing Last Responsible Moment must be developed into a skill (Lane and Woodman, 2000). Indeed, it may be carried even further into how to manage changes in general. Also Value Engineering must be redefined from managing the process to delivering the specified value to the lowest cost and into how to meet the expected value criteria at an acceptable price. Along with these challenges comes the requirement for reduced project delivery time. Empire State Building was built in 13 months and under budget; how would we compete with this, seventy years later? We may even be met by tighter schedules in the future.[12]

Minimize Waste

Ohno (1978) identifies these seven sources of waste in production:

- overproduction
- waiting
- transportation
- processing
- inventory
- movement
- making defective product

Koskela (2004) as well as Macomber and Howell (2004) suggest more sources of waste in construction. Koskela (2004) suggests “Make Do” as one whereas Macomber and Howell (2004) suggest “Not Listening” and “Not Speaking” as another two great wastes. Indeed, life seems to be rich in waste.

This opens a more general discussion on the application of Ohno’s seven sources of waste. First it can be argued that each of the seven sources expresses the transformation or the flow point of view – or rather the operations and process points as expressed by Shingo (1987).[13] But are they always waste from a flow or value

[12] Indeed, an analysis of the Empire State building process in the light our T-F-V understanding of the construction process may be very fruitful.

[13] Where Koskela talks about production as transformation and flow, Shingo understands it as operations and processes. In doing so, Operations are more than the mere transformation of the materials but also transport, inspection and waiting – that is all the individual steps in the production. Minimizing

perspective in a complex and dynamic system? Are they waste at all or just buffers to protect work packages against turbulent flows? Or in what setting are they waste? It seems like we are looking at risk analysis here.

The two proposals for further sources of waste leave us with the key question: what is waste in a complex system? Ohno's understanding is obviously founded in the ordered world of production, where operations not generating value can be identified and eliminated. But if the system is unpredictable, which operations are then wasteful? We may know it *after* we observe the system's behavior. However, the system will behave differently the next time we observe it because of its complexity, leaving us with same question. Over time, we may learn that some operations seem to be wasteful as they are never found useful. But why then is the author carrying a hard hat on construction sites, when over more than forty years nothing hard has hit his head? The Danish physicist Per Bak stated it this way: 'The likelihood that something unlikely will happen is great because so much unlikely may happen.' If this is the case, prudence towards which events are waste? Even making errors may be of value when treated as an instrument for learning.

Koskela's proposal of waste of 'making do' is dealing with the waste associated with starting an assignment without having all the necessary prerequisites available. And he is right – at least from a rational productivity point of view. But how does this apply in a complex and dynamic setting? In spite of being short of say the best equipment or the optimal crew, an activity may be urgently important in order to further the flow of work to teams waiting downstream. 'Make do' is then waste from a transformation point of view, but may be very beneficial from a flow point – as long as the outcome in terms of quality and safety is acceptable. According to Freedman (2000), the US Marines act on 70% of the total information as a general rule, which must be seen as 'make do' in an extremely complex and dynamic setting.

The seven sources are indeed sources of waste in an ordered system, and it is easy to recognize that they are often also so in construction. So we should of course try to minimize them, but not by just eliminating them rather by reducing the possible need for them by increasing order in the actual situation.

This casts the larger question about waste and the need for waste. Nature – probably our most complex system – is rich in waste. Seeds, fish, insects and small animals are spread in abundance and most are lost in the process. Buffers – waiting – are all around in nature's systems. Not only waiting for spring, but also waiting for rain to come and transportation as a means for spreading the outcome of one production to new sites. Even nature makes defective products which, at least according to Darwin, is one of the instruments for learning and for the development of new and better 'products'. So if we accept the complex and dynamic nature of construction, we should look more carefully into the value of waste.

Nature uses waste in almost any situation, but nature is not under any general control as construction projects are supposed to be. Again, accepting construction as a complex and dynamic kind of production we must also accept that there may be an optimal amount of waste in any construction project depending on its nature and that trying to reduce this amount of waste may jeopardize the flow of work. Bak (1996) as discussed further in the next section argues that small 'accidents' which from a control point of view may be seen as waste is a means for learning within the system.

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waste according to Shingo is first an issue of eliminating operations not needed and *then* making the rest more efficient. 'Do the right things before doing things right'.

Macomber and Howell's idea of Two Great Sources takes us even further in the complex system thinking, but where should discussions end and the work get done? Obviously even speaking and listening – and therefore not acting – may be sources of waste. According to Freedman (2000), the US Corps of Marines seems to think so in letting their forces at the site act without speaking and listening (providing information, and asking and waiting for orders).

In dealing with waste we should therefore adopt Shingo's principle of optimizing the system as a whole before making its details more efficient. In a complex system we should also recognize that the optimal state of the system as a whole is suboptimal for almost all of its parts.

Managing Flow and Buffers

The introduction of the concept of flow is probably the most important contribution to the understanding of the construction process made by Lean Construction. Koskela (2000) identifies seven flows towards the perfect execution of a work package: Previous work, space, crew, equipment, information, materials, and external conditions such as the weather. Each of these seven flows has its own nature and therefore its own uncertainties, which give rise to its variability or turbulence and each of these seven flows should therefore be managed with respect to its own nature.

Buffers are means to reduce the impact of variability in flows (Hopp and Spearman, 2000). However, buffers in manufacturing are generally seen as a non value adding cost, and they should therefore be minimized. Indeed, Shingo (1987) talks about "non-stock-production" and Toyota – the world leader in lean (car) production seems to have reduced their need for buffers through stop-the-line and just-in-time pull logistics. On the other hand, Toyota has also introduced substantial buffers in their product design process in the form of alternatives that are kept active longer than any other major car manufacturer (Darsø, 2001).

This can be seen as a waste of overproduction or as a buffer depending on whether the alternative might be useful for some future model, but it demonstrates that factory physics' rigid principles or Ohno's understanding of waste of overproduction do not hold true in the complex and dynamic situation of designing new car models. The seven flows identified by Koskela should therefore be studied independently and their nature understood much deeper, leading to proposal of new instruments for their management in a complex setting.

The Last Planner system is primarily seen as a tool for *managing the flow of work* – the first of Koskela's seven flows. It is the tool that has given Lean Construction in general a high esteem in the industry and it seems to work well indeed. However, even though it looks like a tool for managing flow of work the underlying premise is primarily a tool for managing turbulence in the supporting six other flows. This is an approach highly different from managing the laminar flows in manufacturing where variability can be kept under control by strategic use of buffers and the foreseen sequence in the flow of work therefore can be kept. In construction, buffers are also used to facilitate reliable workflow by ensuring that there is always work packages ready, i.e., constraint-free but at the same time it is recognized that frequent adjustments of the work sequence may be needed because of the turbulence in the supporting flows and such adjustments are authorized through the weekly work plan process, which takes place as a conversation between the trades.

Last planner's use of buffers in the flow of work in the form of 'work packages made ready', i.e. released from the previous trade may be an expensive kind of buffer not least in fast track projects. In general, the use of buffers is a trade off against the benefit of single piece flow as an instrument for detecting errors and meeting the market's ever increasing demand for faster project completion. A buffer strategy dealing with all seven flows in a systematic, more balanced and controlled way may be much more beneficial and a deeper understanding of each of the six other flows and development of adequate tools for their management are therefore of great importance.

The physical flow of *materials* is probably the easiest to deal with. Even though as shown by Arbulu and Ballard (2004) this may also be seen as a near-turbulent flow, somewhere in their flow towards the construction site the materials meet the real turbulent construction project, and this point should be understood in deeper detail as the de-coupling point between the two kinds of production wherein a new kind of buffer management should be established. Experiments with a rigidly controlled acceptance of flow of materials and equipment into the construction site may be combined with off-site 'central' staging areas, either at the wholesale dealers' facilities or as arrangement for the project in question have shown a great potential for improved material flow control along with an improvement of the flow of space (Bertelsen and Nielsen, 1997; Arbulu et al, 2003; Arbulu and Ballard, 2004).

However, the benefit of the use of permanent central storages – or material hubs – for a number of construction projects within the same area has not been investigated, even though this is one of reason for the low costs of logistics in almost any chain of supermarkets.[14] One important issue in the use of central storage in the flow of materials is that in most projects it is known what will be used but not when. The central storage decouples nicely these two flows of information: what and when. As costs of transportation counts for app. thirty percent of the costs of building materials, which again counts for two thirds of the construction costs, there seems to be a great potential for cost reductions in this flow (Bertelsen, 1993 and 1994).

Management of *space* is quite different. Most construction sites are short on excess space or if they have it then its use increases the cost of internal transportation. This kind of flow management – the handing over of space from one trade to another – is quite complicated to manage because of the dynamics of the work flow. Some studies have looked into the management of space by 4D modeling but as there have been no recent IGLC reports on this approach, one may speculate on its feasibility with the current state of the technology.

Another – and perhaps more promising method – is the use of the line-of-balance planning methods, which until recently have been little explored (Seppänen and Junnonen, 2004). This method has been re-introduced as an alternative to methods such as CPM for the management of the flow of work, even though line-of-balance is primarily a tool for management of the flow of space. Not least in repetitive projects such as the interior works in apartments, offices or hotels this may be a useful tool.

But also more simple instruments may be used. Mastroianni and Abdelhamid (2003) describe the Last Planner implementation on construction work for Ford Motor

[14] At a meeting in the Danish Lumber merchants' association Mr. Steen Gede, president of Dagrofa – a major Danish supplier to independent supermarkets – gave a very simple but convincing example of how central storages might increase construction supply service and at the same time reduce the costs of transportation with as much as eighty percent.

Company where the general contractor used the floor plan as a basis for the weekly work plan and marked on it the location of crews using the space in the coming week. A similar approach has recently been taken by the Danish Broadcast Corporation. Also strategies to keep all components stored at the manufacturers or at the off site staging area in stead of just having them 'throwing their output over the wall', may reduce the need for space substantially just as looking closer into off-site fabrication of bigger modules and systems may do (Pasquire and Connolly, 2002 and 2003).

But how to manage the flows of *crew* and *equipment* in a highly dynamic system? Crews are, in particular, an extremely expensive and harder flow to buffer because they are shared with other construction projects. Ballard (1999) suggests the improvement of the flow of work by introducing 'waste' by overcapacity. Waste for the individual trade may be of value for the whole, but how are such principles managed in a subcontracted project organization where every sub-contractor tries to get a profit in a highly competitive environment?

The complex flow of decisions – and thereby *information* – is yet another game. This flow ties deeply into the client's complex situation of being a sub-project to "someone else's complex and dynamic project." British Airport Authorities has developed the concept of Last Responsible Moment (Lane and Woodmann, 2000) as an instrument to manage the flow of decisions. Decisions in the client's turbulent environment cannot be buffered, so the best strategy is to identify critical decisions and by working backwards in the CPM-plan for the flow of work identify the last responsible moment for the decision in question. One may say that this is a trade off between a construction time buffer and a decision time buffer. But where should this trade off be made? It is indeed a trade-off between making the wrong decision and getting the project delayed – or completed at excess costs. It looks like the trade off Toyota makes in keeping design alternatives for critical modules open for as long as possible where the trade off takes place between design costs and developing time (Darsø, 2001). But Last Responsible Moment is a much more complex trade off because of the lack of modularization in construction.

Manufacturers of long lead items for construction projects often have problems with meeting the uncertain and turbulent construction process (Elfving at al, 2002, 2003 and 2004). Strategies for de-coupling here should be understood in a new perspective. One such strategy may be to separate the ordering of production capacity from the submission of the precise product specifications, for instance order production capacity for the electrical switchboards early in the process but not submitting the detailed specifications until late, when the whole design is settled (Elfving et al 2004). Indeed, managing this interface may be of great importance to project management.

The flow of 'the rest' – the *external conditions* – is mostly the flow of unlikely things that may happen. Can this flow be managed at all? The answer is both yes and no. Some disturbances can be foreseen such as the weather – at least for the week to come. Some might be foreseen and proper action taken such as the time for obtaining the approval from the authorities.[15] But much more may happen, and managing this

[15] In some recent Danish projects dealing with the rehabilitation of listed town houses, the municipality was directly involved in the design process and thus became a party of the solution instead of a party of the problem. As a result, the approval went easily through the town council.

flow is really an issue of not thinking of an ordered process and specific risks but looking at the total amount of uncertainties. Indeed, a new role for project management.

Project Management and Control

Construction management is by tradition executed as a management of transformations (Koskela and Howell, 2002) and as such can be interpreted as management by contracts. This kind of management may work in a rational and ordered system – it is in its nature a management by plans – but in a setting where reliable plans can not be made, management must be understood in a new way.

Per Bak (1996) introduces the importance in complex and dynamic systems of *not* keeping the system under tight control. He advocates that a frequent number of small – but acceptable – unforeseen or not wanted incidents are taking the stress out of the system and thereby contributing to avoid the large and fatal accidents. His outset is earth quakes – actually experiments with sand piles – but he argues the same idea convincingly in cases such as the collapse of the Eastern European economies. As a matter of fact, the same thinking can be deducted from the managing principles in the US Marines, where acting in the situation given is mandatory and where mistakes therefore are accepted (Freedman, 2000). Indeed, the Marines' – and other military units' – management principles may be a great source for inspiration. War is probably the ultimate complex system from a management perspective and military management principles are based on the principle that fighting cannot be managed in detail in a top down way.

Similar principles may be found when looking closer at the Japanese production system. Stop-the-line expresses in its own way a management by the system's status and therefore delegates the responsibility to the individual worker in the same way as quality control by poka yoke and single piece flow. The overlaid strategy is defined by the product and the production system – just as the strategy for the battle is laid out by the head quarters – but the operations are managed by the group at the site.

In construction these ideas lead to managing bottom up and not top down only. Last Planner can be seen as one approach to this kind of management, transferring responsibility for the operations to the lowest level possible while focusing the middle management's own resources on managing the logistics (Look Ahead Plan) and establish the over all strategy (Phase Schedule).

Even though these tools seem well suited for the complex construction process, some elements may be missing. The unique nature of any construction project – not only from a product perspective but from a construction team perspective as well – leads to a focus on the learning metaphor. The construction project must be seen as a learning process, where the crews and the organization as a whole are learning. They are continuously learning about the object, the process and the objectives, and also learning about each other. This gives rise to a completely new kind of project management. In addition to managing operations, management should now focus on managing flow and on managing cooperation and learning. This is not only in order to increase productivity but also because managing the generation of value comes more and more into focus and the process carries quite an amount of value in its own right.

Macomber and Howell (2003 and 2004) suggest based on Flores (1982) that management should take place by a series of conversations, where requests are made and promises given. This approach is similar to the one adopted in the Danish implementations of value management (Emmit et al, 2004), and not least of Last Planner (Bertelsen and Koskela, 2002) where it has also shown efficiency in the preparation of the weekly workplan. However, there seems to be some more reluctance to get the conversations going in the Lookahead planning process. One reason for this may be that the crews immediately recognize the benefits of the coordination, whereas the superintendents often are very busy and they also consider the Lookahead plan their own business. Future developments in the implementation of the Lookahead process should consider that subcontractors tend to aim at reducing waste in their own operations without any understanding of the importance of the flow. Once again learning is needed.

Managing complex systems is a new skill. Nature does it fairly well and may be Per Bak is right when he states that less control makes the system operate better. But how far is it possible to establish a self organized and learning system? Kreiner (2004) claims that in some cases less planning may be a better solution and Last Planner may be seen as an implementation of that principle. In managing projects under such conditions, the following seven steps are worth careful consideration:

- Improve the system before its details
- Increase order as much as possible but do not expect a perfect situation
- Set clear objectives and communicate them widely
- Improve the logistics
- Reduce the size of the window-of-order needed for the operations
- Manage the operations bottom up
- Welcome errors as an opportunity for learning – they will occur in spite of what you do, and they will probably be smaller and more acceptable than otherwise.

Managing Quality

Construction is ill reputed for the quality of its output. A recent Danish report estimates the cost of errors in construction to more than ten percent of industry's total production value (Erhvervs- og Byggestyrelsen, 2004). Some errors may certainly be caused by the unique product but quite a few are caused by bad craftsmanship or more probably by a system letting bad craftsmanship occur and slip through.

At least in the Nordic countries the skilled construction labor is highly qualified but still the quality of the construction output is low. This makes one speculate whether there are some mechanisms in the production system which causes this – beside sloppiness by the individual craftsman. Some experiences, albeit a few, seem to confirm this. When PPC is used as a poka yoke instrument in asking the crew who take over the work to state whether the work package was completed and completed correct, the quality seems to improve (Misfeldt and Bonke, 2004). This approach to quality assurance changes the view from the traditional QA focus on the single error and its cause, to the system from which errors in general emerge.

Thereby the traditional top down management is substituted with a bottom up responsibility in accordance with the commitment-making underlying Last Planner. The new management principles improve the quality with an outset in improving flow of work. In the words of complexity one may argue that the low quality in construction is an emergent phenomenon – it is not caused by a single chain of events but grows out of the system and the way it is managed.

Managing Safety

Another huge problem in construction in almost any country is workers safety. Construction is badly reputed by its high accident rate and even strong efforts in the form of regulations, control, education and information campaigns, have had minor effect only (Howell et al, 2002).

Here one may also argue that the understanding of accidents may be incomplete, and even incorrect, in the traditional approach to workers' safety, because it is based on a rational understanding seeking to detect the dangerous routes to accidents. Looking with the eyes of Per Bak, one may argue that unlikely things such as accidents happen due to so many possible events that can happen. Once again we see an emergent phenomenon, in this case the accidents.

Following this line of thinking, the proper approach to safety is not to impose more rules but to change the system's behavior into being safer. Howell et al. (2002) propose a deeper understanding of safety in the light of complexity and introduce a safety management framework based on Rasmussen (1997).

The Danish experiences with the use of Last Planner shows that a proper implementation of its principles substantially improves safety (Thomassen, 2002). One reason for this may be that managing complex systems requires a bottom-up approach to management, wherein responsibility is distributed and where cooperation becomes important (Howell et al. 2002, Howell and Macomber 2003). In these implementations the meaning of the term 'completed' is extended to also include that excess materials and waste are removed and the location is clear for the next team with all the safety measures in place. This – along with the direct involvement of the crews in the work planning as seen in the Danish implementations of Last Planner – inevitably leads to a process where safety no longer is just a matter of obeying rules but of taking charge of the health of your fellow workers.

A special features of operating in this way is the extension of the sound activity concept to include not only that all the seven preconditions are in order but that the 'space' is safe, the 'crew' has the right qualifications and certificates, and the 'equipment' is safe and well-maintained, etc.

Conclusion

What Kind of Production is Construction was the title of a paper by Glenn Ballard and Gregory Howell (Ballard and Howell, 1998). In this they opened the question of the nature of construction and proposed that construction should not be compared to manufacturing as much as to design and prototyping. In their paper they argued that even if elements of construction successively were turned into manufacturing there would always be reminders that could not be made lean production and that these reminders were the true characteristics of the construction process. The complex nature of construction may be an important argument for this, not least because of the complexity of the client in the value generation.

Abdelhamid (2004) suggests that the present change in the understanding of the construction process is a shift of the underlying paradigm governing construction management. From a pure transformation view the paradigm is moving through the T-

F-V view and into the understanding of construction as a complex and dynamic system, where cooperation and learning become the guiding metaphors.

This new understanding opens up for several areas, where research is needed as discussed above. This research should aim at re-interpreting the construction process and to develop new and better principles and methods for its management.

Some key research questions may be:

- Complex systems' nature – their different states and the phase transition between chaos and order; the nature of emergence, self organising capabilities and learning
- Complexity in construction – not least in the client and the production systems
- Value and value generation – the concept of value and the nature of wicked problems
- Modularization – strategies for making construction a manufacturing; cases and experiences
- Waste in complex systems – what is waste and how to utilize the value embedded in waste
- Laminar or turbulent – the characteristics of each of the seven flows (Koskela's seven activity pre-requisites) and their predictability horizon; including tools for flow and buffer management
- Errors and accidents – emergent phenomena to be understood in a new way

A deeper understanding within these areas should be an important part of any research agenda, but from a wider perspective the outlined Product and Process strategies for the development of the construction process may be of much more importance.

Elements of both strategies will come. Parts of the construction process will inevitably turn into industrial manufacturing where an increasing challenge for the remaining, chaotic process will be how to handle the interface, not how to optimize the manufacturing flow. As parts of construction turns into manufacturing, we may as well give up the manufacturing of these parts as the areas for our lean construction research. Manufacturing has been around for more than a centennial and has made strides in understanding its factory physics. How can we in construction claim that we know better just because the manufactured product is used as a component in a construction process? Some may, but they have then turned into experts in manufacturing.

The construction process we all study, for the most part, is not manufacturing at all. The great challenge for Lean Construction in the years to come is not to turn construction into a manufacturing process, but to keep focus on the construction process with respect to its millennium old art of construction. Indeed, our challenge will be to support our architect colleagues in their endeavor to establish the best built environment possible for us and for the generations to come.

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