EXPLORING THE CONNECTION BETWEEN OPEN BUILDING AND LEAN CONSTRUCTION: DEFINING A POSTPONEMENT STRATEGY FOR SUPPLY CHAIN MANAGEMENT

RubenVrijhoef[1], Ype Cuperus[2] and Hans Voordijk[3]

ABSTRACT

Open Building has been known as a building concept characterized by an explicit customer focus, modular pre-engineered product system, and a sequential process structure. Open Building advocates a concept of modularity, which includes the separation of different levels of decision-making, and the decoupling of building parts within a modular system. The process of Open Building is characterized by a systematic and interconnected sequence from interactive client specification of the built object, through components manufacturing, to site assembly, supported by a uniform product and information management system.

In essence Open Building applies lean manufacturing concepts and techniques to the delivery of a building. Therefore, the characteristics of Open Building and Lean Construction are being compared on a number of basic aspects, including order fulfillment, components manufacturing, materials distribution and assembly, in order to find similarities and differences, and to explore the connection between the two concepts.

The connection between Open Building and Lean Construction is found in the similarities of the way the supply chain is organized and managed. By its specific product and process co-ordination, Open Building implicitly prescribes a specific organization of the supply chain. This is characterized as a postponement strategy for supply chain management, by its delayed differentiation strategy.

KEY WORDS

Lean Construction, Open Building, supply chain management, postponement strategy, delayed differentiation strategy.

---

[1] PhD Researcher, Department of Project Management and Real Estate, Faculty of Architecture, Delft University of Technology, PO Box 5043, NL-2600 GA Delft, The Netherlands, Phone +31 15 2783049, Fax +31 15 2783171, E-mail r.vrijhoef@bk.tudelft.nl

[2] Director, OBOM Research Group, Faculty of Architecture, Delft University of Technology, De Vries van Heystplantsoen 2, NL-2628 RZ Delft, The Netherlands, Phone +31 15 2785400, Fax +31 15 2788295, E-mail y.j.cuperus@bk.tudelft.nl

[3] Associate Professor, University of Twente, Faculty of Technology and Management, Dept. of Construction Process Management, P.O. Box 217, NL-7500 AE Enschede, The Netherlands, Phone +31 53 4894214, Fax +31 53 4892511, E-mail h.voordijk@sms.utwente.nl

INTRODUCTION

Open Building and Lean Construction are concepts that have been existing independently, and that have been interrelated few times (Cuperus 2001). This paper aims to explore the two concepts and compare them in order to find the differences and similarities between Open Building and Lean Construction. The combination of the two concepts, while having different viewpoints and objectives, is found in the concept of supply chain management. From the lean construction perspective, Open Building can be explained and typified as a postponement strategy that promotes flexibility and agility in the building process and product by delayed differentiation. The differentiation strategy is supported by a structured and integrated system of decoupling of interconnected parts (units) of the product process and the product.

In fact, construction supply chain management can be characterized as a postponement strategy for delayed differentiation in the order fulfillment process, similar to “pulled production”. Open Building can be indicated as such a postponement strategy, by advocating a building product and process system of separation and decoupling of different levels of decision-making, and modular coordination of the structure of the product structure corresponding to the structure of the process (O’Brien et al. 2002).

In the first and second section of this paper, the concepts of Lean Construction and Open Building are discussed. In the third part, both concepts are compared and analyzed by using the postponement strategy. The paper is finished off with conclusions on the similarities and differences between the two concepts.

LEAN CONSTRUCTION

LEAN AND AGILE PRODUCTION

Lean has been described as “doing more with less”. Lean Production strives towards zero inventory and just-in-time logistics (Womack et al. 1990). The origins of Lean Production can be traced to the Toyota Production System (TPS), with its focus on the reduction and elimination of waste (Ohno 1988). Fundamental principles of Lean Production include (e.g. Koskela 1992):

- Identify and deliver value to the customer value by eliminating activities that do not add value.
- Organize production as a continuous flow.
- Perfect the product and create reliable flow through stopping the line, pulling inventory, and distributing information and decision making.
- Pursue perfection by delivering on order a product which meets customer requirements with nothing in inventory.

Christopher and Towill (2000) argue that agility is a “business-wide capability” that embraces organisational structures, information systems, logistics processes and, in particular, mindsets. More than lean, agile is focussed on flexibility and responsiveness. The origins of agility as a business concept lie in flexible manufacturing systems. Initially it was thought that the route to flexibility was through automation to enable rapid change (i.e. reduced set-up times) and thus a greater responsiveness to changes in product mix or volume. Later this idea of manufacturing flexibility was extended into the wider business context of agility (Nagel and Dove 1991). In circumstances when demand is not highly volatile, agility could be called a subset of lean.

Both agility and lean demand high levels of product quality. They also require minimum total lead-times defined as the time taken from a customer raising a request for a product or service until it is delivered. Total lead-time has to be minimized to enable agility, as demand is highly volatile and thus difficult to forecast. If a supply chain has long end-to-end lead-time then it will not be able to respond quickly enough to exploit marketplace demand. Furthermore effective engineering of cycle time reduction always leads to significant bottom line improvements in manufacturing costs and productivity (Towill 1996).

Lean supply

In the supply chain, as part of Lean Production, components flow from the supply base through supplier tiers towards the assembler. The components are delivered to fit exactly to the structure of the product system and production process of the assembler. Typically, the suppliers are organized in a pyramid of tiers. The first tier supplier integrates all lower tier supplies and develops complete subsystems that fit together with the other subsystems that the assembler eventually assembles into the end product. This is based on cooperative and intensive relationships between the assembler and suppliers (Womack et al. 1990, Lamming 1993).

Lean supply relates to supply chain management in the way that both concepts endeavor to mobilize and exploit expertise en competencies wherever they lie in the supply chain, and to recognize and channel the activities and impacts in one part of the supply chain made in another (Lamming 1996). This has previously also been defined as interdependency within the supply chain.

LEAN CONSTRUCTION

In essence, Lean Construction emerges from the application of a new production philosophy to construction (Koskela 1992). For the building industry, this philosophy means a massive shift whereas in manufacturing industries lean has been defined much more narrowly while many of those already had theories of production. Essential features of Lean Construction include a clear set of objectives for the delivery process, aimed at maximizing performance for the customer at the project level, concurrent design of product and process, and the application of production control throughout the life of the product from design to delivery (Howell 1999). The concept of Lean Production includes or implies various concepts continuous improvement, increased process transparency, increased output customer value, elimination of waste and variability, efficient use of resources and production control. These concepts apply also to the supply chain and they form a basis for supply chain management.

In the construction industry, the overall diffusion of the new philosophy is still rather limited and its applications are partial, especially when the construction supply chain is observed, which is often still highly fragmented. Quality assurance and TQM have been adopted by a growing number of organizations in construction, first in materials and components manufacturing, and later in design and construction. Further initiatives undertaken in several countries have been trying to alleviate problems associated with construction's peculiarities. The one-off production feature of the construction industry has sometimes been reduced through more standardization, modular coordination and multi-project partnering arrangements between parties. Difficulties of site production have sometimes been alleviated through increased prefabrication, decoupling of building components and systems, and deployment of multi-skilled site crews. This underpins the need to design a production system that will deliver a customized product through a well structured process with predefined interfaces.

OPEN BUILDING

The concept of Open Building identifies the conflict between the inertia of the building industry and the volatile customer demand. It suggests distinguishing different levels of decision making, in order to decouple building parts with different life cycles, controlled by different parties, built by different trades. In order to decouple and yet co-ordinate, a set of rules was developed for dimensioning, positioning and interfacing pre-engineered building systems. This offers a basis for a systematic building process with predefined interfaces between activities that supports the transformation of the building process into an assembly process, which is a key factor for waste reduction and Lean Construction (Cuperus 2001).

According to Dekker (1998) the basic idea of Open Building is a principle of organizing the building process along independent levels of decision making, corresponding to the structure of technical subsystems in order to create maximal flexibility and variety of the object, while keeping the process systematically organized. In this way, it enables relatively free choice of design of one level, independently from the underlying level, i.e. the infill level (fit-out, interior) and the support level (base-building, structure) of a house. This decoupling of subsystems allows independent decision making regarding the base-building and the fit-out, and thus supports delaying decisions on the fit-out, while the base-building is already built. In addition, it allows residents to easily refurbish and restyle their houses during occupation, or in case of change of residents. By involving the residents in the decision process, Open Building is a customer focussed way of building, serving the ultimate customer, and beyond (Dekker 1998).

MODULARITY

A basic aspect of Open Building is the modularity of the building system into subsystems and parts. Modularity has been defined as ‘a particular pattern of relationships between elements in a set of parameters, tasks or operators/people, a nested hierarchical structure of interrelationships among the primary elements of the set’ (Baldwin and Clark 2000).

Modularity decreases the complexity of constructions themselves. The essence of a modular product is that its parts are interrelated, different parts must work together. The whole is more than a subset of its parts.

Modularity in design and engineering means designing interacting modules using design rules: guidelines for partition of effort and knowledge. After implementation modularity potentially reduces costs of experimenting with new designs. It creates the possibility of (ex)changing pieces without redoing the whole (i.e. waste). Design and its results become flexible and capable of evolving at the modular level. Modular structures are complex structures built up of simple structures. Complex changes occur as a result of combinations and sequences of simple changes. Modular operators of such complex adaptive system are (Baldwin and Clark 2000):

- splitting the system into modules

- substituting one module design from another
- augmenting, adding new modules to the system
- excluding a module from the system
- inverting to create new design rules
- porting a module to another system

Modularity and industrial organisation

Modularity affects the relation between design of objects and the structure of industry. Both artifacts and firms evolve interactively over time to create a "complex adaptive system" which we call "an industry" (Baldwin and Clark 2000). There is a close relationship between the structure of design and economic structure of firms and markets (Voordijk 1999, 2000). Large-scale modularity of the construction product changes the industry structure into "modular clusters". Along the different types of modules the industry will be divided into a cluster of sub-markets. Value is created by new distribution of roles and work structuring among designers, producers and investors. Users and suppliers of equipment would have to co-invest in the design architecture. High levels of co-investment by these parties are indicative of architecture's success.

PRODUCTION AND LOGISTICS MANAGEMENT

In terms of clusters and sub-markets, in the supply chain of Open Building the dual concept of two separate types of contractors is often introduced: a contractor for the base-building, and a contractor for the fit-out, including separation of tasks and contracts. In the supply chain the structural contractor precedes the fit-out contractor. The interface is supported by standards so that the fit-out corresponds to the base-building, and vice versa. This is relieved by the modularity advocated by Open Building, that is an "open network system" with a "dispersed control pattern" of making and buying parts in the supply (and production) chain (Kendall 1994, 1990). An additional argument of Open Building is the difference of life cycle between the base-building and the fit-out, which needs the fit-out being modularly separated and separable from the fit-out.

The fit-out is a modular system prefabricated and supplied by a single supplier. Supplier is often also the fit-out contractor assembling and installing the fit-out on site into the base-building. The modular system is developed and pre-engineered in such a way that it can be assembled and installed fast and simply. The customers can often select and order there fit-out directly from the fit-out supplier/contractor. The modular system allows finishing according to the customers' wishes. The customer is involved in an interactive decision process to design the fit-out. Next the fit-out supplier/contractor start the engineering, prefabrication and supply process, towards site assembly and installation (Tarpio and Tiuri 2001)

The supply of the prefabricated parts is bundled in a "package". The parts are coded, fitting exactly and easy to assemble and install, so on-site activities and "improvisation" are minimized. The assembly and installation is executed by a small, well trained, multidisciplinary work crew. The crew needs a couple of weeks to finish the total fit-out. For example, the Dutch fit-out system Matura provides a complete floor system including all wiring and drains, and the fittings, partition walls, fit-out doors etc. (Dekker 1998). The system is installed by a multidisciplinary crew of three craftsmen, each specialized to execute one or more jobs, e.g. M&E, HVAC, tiling and carpentry, etc. The Matura system is installed in an average size apartment by the crew of three craftsmen within 10 working days.

Altogether, Open Building needs adaptation and reconfiguration of the supply side to support its postponement strategy of modularity, delayed differentiation, and decoupling of subsystems and decision levels (Dekker 1998).

SUPPLY CHAIN MANAGEMENT

Christopher (1992) observes that 'supply chain management covers the flow of goods from supplier through manufacturing and distribution chains to the end user'. The concept of supply chain management (SCM) means that independent firms agree upon the way in which production and information flows are organized. The consequence of this agreement is an integrated organization of logistical activities within a chain or group of firms. Recent research on supply management has focused on a debate regarding the need for closer relationships between customers, suppliers and other relevant parties, in the search for competitive advantage. Fundamental to the theory of supply chain management is the notion of interlinking and exercising control of an identified sequence of interdependent activities and/or firms.

POSTPONEMENT

According to Bowersox and Closs (1996), the principle of postponement can be subdivided into three generic types: form, time and place postponement.

- Form postponement entails delaying activities that determine the form and function of products in the chain until customer orders have been received.
- Time postponement means delaying the forward movement of goods until customer orders have been received.
- Place postponement refers to the positioning of inventories upstream in centralized manufacturing or distribution operations, to postpone the forward or downstream movement of goods.

Postponed manufacturing combines these three types of postponement. In other words: final processing and manufacturing activities are postponed until customer orders have been received (time postponement) and are performed from central locations in the international supply chain (place postponement) to include customer and country specific characteristics in the finished product based on final manufacturing (form postponement), frequently followed by direct shipment to retailers or customers. This operating system is diametrically opposed to push systems in which goods are entirely manufactured in anticipation of future customer orders and stored downstream in the supply chain, even though the company does not know whether a customer will actually buy the product (Van Hoek 1999).

DECOUPLING OF THE SUPPLY CHAIN STRUCTURE

In other industries, the decoupling of different production channels and postponement are applied to the configuration of the supply chain as a part of supply chain management and outsourcing policies to support the integrated production control and improvement of the supply chain (Van Hoek 1997, 1999).

The decoupling point plays an important role in defining the supply chain that is both lean and agile. The decoupling point has been defined as the point in the supply chain that separates the part of the supply chain oriented towards customer orders from the part of the supply chain based on planning (Hoekstra and Romme 1992). In manufacturing, it is commonly associated with the strategic stock that buffers the supply chain from changes in customer demand, in terms of both volume and variety. Associated with the decoupling point is the issue of postponement and late configuration. As seen in figure 1, there are two extreme positions.

The first is the 'buy to order' supply chain in which the product is configured from the outset, that is, from raw materials. In this supply chain all businesses are agile and all respond to changing customer requirements. This supply chain works well as long as the customer is willing to accept long lead-times. The other extreme is the 'ship to order' structure in which a standard product is provided from a defined range. Although lead-times are very short (or 'off the shelf'), the danger of obsolescence has to be considered.

Naim et al. (1999) highlight the potential for applying standard components and the importance of the location of the decoupling point in house building supply chains in order to develop "leagile" house building supply chains, and postponement strategy that enables to respond to changing customer requirements in an efficient way. This approach needs holistic supply chain reorganization and increase of the level of customization. Barriers to these developments include institutional factors, implications for internal business processes, fragmentation of the supply chain, low innovative capacity, and low technological competence (Naim et al. 1999).

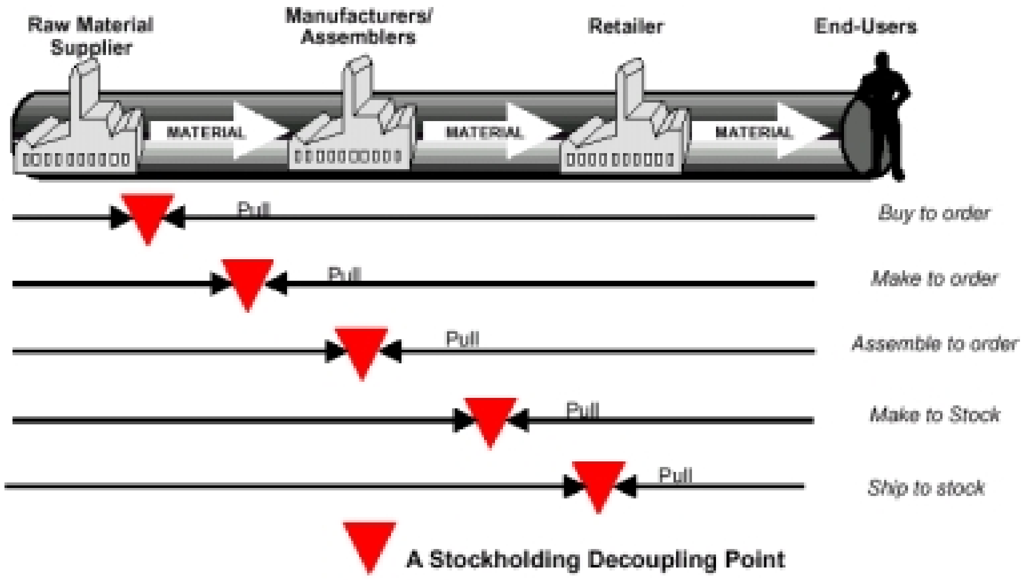

Figure 1: Family of supply chain structures (Hoekstra and Romme 1992)

Lin and Shaw (1998), define three types of supply chain networks (SCN) including three types of strategies towards the order fulfilment process (OFP), including order management, manufacturing and distribution. The first type is convergent supply chain implying a make-to-stock strategy and early differentiation, e.g. in the agriculture industry. The second type is the divergent supply chain implying a make-to-order strategy and delayed differentiation, e.g. in the computer industry. The third type is also a divergent supply chain, but it implies a build-to-forecast strategy and responsiveness, e.g. in the textile industry. Applying modularity to the product design, the outsourcing of components, and the organisation of production and supplies, is viewed as an improvement strategy of the OFP and SCN structure (Lin and Shaw 1998).

CONSTRUCTION SUPPLY CHAIN

Construction supply chains have been associated to make-to-order supply chains (e.g. Vrijhoef and Koskela 2000). Typically, a make-to-order construction delivery process begins at the customer, through the entire supply chain from initiative to hand-over, back to the customer. In contrast to most manufacturing supply chains, a construction make-to-order supply chain is converging to the construction site where the one-off final product is assembled. Converging chains have been typified by these characteristics (Luhtala et al. 1994):

- Type of business: project deliveries
- Production: make-to-order
- Control: pull
- Volumes: low
- Products: investment goods
- Customer focus: single customer
- Cost savings potential: project management
- Production objectives: quality, punctuality, delivery time

Luhtala et al. (1994) argue that pure converging chains occur in one-of-kind production and in project delivery business, such as construction. In addition, the competence in make-to-order supply chains is merely based on technical know-how, and managerial issues like information exchange and co-operation between units in the supply chain.

CONNECTION BETWEEN OPEN BUILDING AND LEAN CONSTRUCTION

In terms of the supply chain, Open Building can be interpreted as a postponement strategy for SCM, while it supports the decision about the fit-out, and thus the most customized part, of the building to be postponed (i.e. delayed differentiation). The subsystems of the building, or at least the fit-out, are made of prefabricated parts that are preinstalled in a manufacturing environment. The decoupling point for the fit-out of the building differs from project to project, and thus needs to be defined clearly for every project. So, the location of the decoupling point is a strategic decision at the beginning of the building process. From there the process is divided in separate paths through the process, involving separate channels through the supply chain, involving separate contractors (or contracts), respectively for the base-building and for the fit-out.

Open Building implies consequences for the supply chain. It is a make-to-order supply chain, which includes a pre-engineered system for the fit-out including standard subsystem and parts, a predefined process and supply chain, client interaction in the design phase of the project, engineering and prefabrication of exactly fitting parts according to client demands, order picking and centralized distribution of all parts per object (house), site assembly and installation of subsystems into the object by a multi-disciplinary work crews.

Open Building involves various aspects of Lean Production. However, the focus of Lean Construction is in general on delivering value to the end customer and achieving waste reduction through the supply chain, e.g. reduction of inventory and buffers in and between stages of the supply chain. On a production level on site, for example, Lean Construction includes just-in-time delivery of materials and reduction of inventory.

COMPARING OPEN BUILDING AND LEAN CONSTRUCTION

Open Building and Lean Construction can be compared on an number of aspects (Table1).

Similarities between Open Building and Lean Production can particularly be observed in the organization of the manufacturing/assembly, logistics and site installation. The distribution of parts and subsystems from suppliers to the site (plant) is characterized by a "pull system" of just-in-time logistics and zero inventory principles. Coding of parts and "kanban" techniques support the distribution, often through a distribution center. On site (plant), Open Building and Lean Production both deploy multi-disciplinary work crews ("quality circles"), including tasks of control of activities and quality.

Table 1: Open Building and Lean Production compared

Aspect	Open Building	Lean Production
Client focus	Client demands and the environment of the object as a structuring principle of the system; client interaction in the design phase of the object	Client demands are met through a predefined yet flexible product system.
Product system	Separation of decision levels and subsystems with different life cycle (most significant: base-building and fit-out); modular coordination between subsystems and parts of the subsystems	Product system allows flexible combining of standardized subsystems and parts
Production control	Organization and coordination of production, and control of parts based on coded system	Pull production; 'Kanban'
Information	Coded system for standard parts of the product and the process; centralized database and information control	Information flow based on pull production from client to supply base
Manufacturing / assembly	Exactly fitting prefabricated parts engineered on basis of product system and according to client demands	First tier suppliers develop and assemble subsystems; second tier suppliers manufacture parts
Distribution / logistics	Supplies, order picking, and JIT transport; parts distributed centralized to site	JIT logistics; 'zero inventory'

Installation	Multi-disciplinary work crew installing all parts, and finishing the object according to client demands	'Quality circles' checking and installing subsystems and assembling the final product

CONCLUSION

Open Building is a concept that supports customized and efficient building through a postponement strategy of delayed differentiation supported by the decoupling and modular coordination of subsystems, the separation of levels of decision making, application of prefabricated parts, and a predefined process organization. The production technologies developed, such as the application of modular coordination, JIT deliveries and site installation of parts and subsystems are familiar to the realms of Lean Construction.

The differences between Open Building and Lean Production include the integrated focus of Open Building on the architecture (including the surroundings), customer (use), life cycle (re-use) and adaptability (flexibility) of a built object. In general, a built object has a longer and differentiated life cycle of subsystems (e.g. base-building versus fit-out), than for instance a car. From the perspective that building is more than just the production of an object, Open Building may therefore be typified as a more "inclusive" or "extended" approach to the built *object* and the building process, for instance in its practical application to a housing project. Lean Construction is based on a general production philosophy of construction that is merely focused on delivering value to the customer by the optimization of the effectiveness and efficiency of the design and construction *process* of a built object, including waste reduction and productivity increase.

Although there are similarities and differences, Open Building – originating from building itself – can gain further from the adoption of Lean Construction principles – originating from manufacturing. The development and implementation of the concept of Lean Construction in turn can profit from Open Building principles. In particular the connection can be made in relation to the development of the construction supply chain, and the definition of a postponement strategy of delayed differentiation for supply chain management.

REFERENCES

Baldwin, C.Y. and Clark, K.B. (2000). Design rules. Volume 1: the power of modularity. MIT, Cambridge MA. 471 p.

Bowersox, D.J. and Closs, D.J. (1996). Logistical management: the integrated supply chain process. McGraw-Hill, New York. 3rd ed., 730 p.

Christopher, M. (1992). Logistics and supply chain management: strategies for reducing cost and improving service. Pitman, London. 294 p.

Christopher M. and Towill, D.R. (2000). "Supply chain migration from lean and functional to agile and customised." *Supply Chain Management: An International Journal* 5 (4), 206-213.

Cuperus, Y. (2001). "An introduction to Open Building." *Proceedings 9th Annual Conference International Group for Lean Construction*, Singapore.

Dekker, K. (1998). "Open building systems: a case study." *Building and Research Information* 26 (5), 311-318.

Grunwald, H.T. and Fortuin, L. (1992). "Many steps towards zero inventory." *European Journal of Operational Research* 59, 359-369.

Hoek, R.I. van (1997). "Postponed manufacturing: a case study in the food supply chain." *Supply Chain Management* 2 (2), 63-75.

Hoek, R.I. van (1999). "Postponement and the reconfiguration challenge for food supply chains." *Supply Chain Management* 4 (1), 18-34.

Hoekstra, S. and Romme, J. (1992). Integral logistics structure: developing customer oriented goods flow. McGraw-Hill, London.

Howell, G.A. (1999). "What is lean construction – 1999." *Proceedings 7th Annual Conference International Group for Lean Construction*, Berkeley, California, 1-10.

Kendall, S. (1990). Control of parts: parts making in the building industry. PhD Dissertation. MIT, Cambridge MA. 238 p.

Kendall, S. (1994). "The concept of control in production chains." White paper. 18 p.

Koskela L. (1992). Application of the new production philosophy to construction. CIFE Technical Report 72, Stanford University. 75 p.

Koskela, L. (1993). "Lean production in construction." *Proceedings 1st International Conference on Lean Construction*, Espoo.

Koskela, L. (2000). An exploration into a theory of production and its application to construction. VTT Publication 408. VTT Building Technology, Espoo. 296 p.

Lamming, R. (1993). Beyond partnership: strategies for innovation and lean supply. Prentice Hall, New York. 299 p.

Lamming, R. (1996). "Squaring lean supply with supply chain management." *International Journal of Operations & Production Management* 16 (2), 183-196.

Lin, F.R. and Shaw, M.J. (1998). "Reengineering the order fulfilment process in supply chain networks." *Int. J. of Flexible Manufacturing Systems* 10 (1998), 197-299.

Luhtala, M. Kilpinen, E., and Anttila, P. (1994). LOGI: managing make-to-order supply chains. Helsinki University of Technology, Espoo. 121 p.

Nagel, R. Dove, R. (1991). 21st century manufacturing enterprise strategy. Incocca Institute, Leigh University.

Naim, M.; Naylor, J. and Barlow, J. (1999). "Developing lean and agile supply chains in the UK housebuilding industry." *Proceedings 7th Annual Conference International Group for Lean Construction*, Berkeley, 159-170.

O'Brien, W.J.; London, K. and Vrijhoef, R. (2002). "Construction supply chain management: a research review and agenda." *10th Annual Conference International Group for Lean Construction*, Gramado, Brazil.

Ohno, T. (1998). The Toyota production system: beyond large scale production. Productivity Press, Cambridge. 143 p.

Pheng, L. S. and Chuan, C. J. (2001). "Just-in-time management in precast concrete construction." *Integrated Manufacturing Systems* 12 (6), 416-429.

Tarpio, J., and Tiuri, U. (2001). Infill systems for residential Open Building: comparison and status report of developments in four countries. Helsinki University of Technology, Espoo. 88 p.

Towill, D.R. (1996). "Time compression and supply chain management a guided tour." *Supply Chain Management* 1 (1), 15-27.

Voordijk, H. (1999). Preconditions and dynamics of logistics networks in the Dutch building industry." *Supply Chain Management: An International Journal* 4 (3), 145-154.

Voordijk, H.; Haan, J. de and Joosten, G.J. (2000). "Changing governance of supply chains in the building industry." *European Journal of Purchasing & Supply Management* 6 (3-4), 217-226.

Vrijhoef, R. and Koskela L. (2000). "The four roles of supply chain management in construction." *European Journal of Purchasing & Supply Management*, 6 (3-4), 169-178.

Womack, J.P.; Jones, D.T. and Roos, D. (1991). The machine that changed the world: the story of lean production. Harper Perennial, New York. 323 p.

Womack, J.P and Jones, D.T. (1996). Lean thinking. Simon & Schuster, New York. 350p.