Value Delivery through *Product Offers*: A Lean Leap in Multi-Storey Timber Housing Construction

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Abstract

Among large Swedish contractors there is currently a specialization trend towards an increased use of prefabrication and complete systems in housing construction. The Lean Construction development up to date has focused on the management of value delivery for complex construction projects. Typical Swedish housing projects do not experience this broad complexity; instead the main challenge seems to be to better specify and deliver customer value. Currently, the Lean Construction methods available are not by themselves enough for the generation of value in Swedish multi-storey housing construction. The aim of this paper is to examine the potential of the *product offer* (a well-defined and highly standardized building system developed from the value views of specific customers) as an aid in the generation and delivery of value for multi-storey timber housing construction.

From the point of view of manufacturing and customer value, the *product offer* is considered a Lean strategy for integrated consideration of internal and external value. Case study experiences indicate that the *product offer* strategy provides stability and continuity for producers that in turn provides with Lean practices in marketing, design and manufacturing. Approaching Lean, small- to medium-sized Swedish producers should focus on improvements through Lean Manufacturing. However, since an emerging demand from the Swedish construction industry forces these producers to take a larger role in the construction process, more construction related Lean improvements must also be considered. In this regard, the *product offer* is demonstrated to be a promising Lean strategy for the Swedish housing industry.

Keywords: Lean thinking, Multi-storey timber housing, Value delivery.

Introduction

In Sweden, there are an increasing number of small to medium sized companies that have specialized in multi-storey housing construction by utilizing extensive prefabrication strategies (Björnfot and Sardén 2006). Among the large contractors, who mainly work in a traditional manner which involves large project organizations and on-site work, a similar trend in specialization is observable. This specialization does mainly concern an increased use of prefabricated construction products as well as long-term stable client relations. Drivers for this specialization trend are a demand for reduced construction costs but also a

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pure business perspective where the higher profitability experienced by specialized companies is sought (10 % compared to about 2 % profitability for the large contractors).

The amount of pure waste in traditional construction projects is striking; a Swedish study reports that only about 20 % of performed work is directly value adding (Josephson and Saukkoriipi 2005). Lean Construction takes on this challenge by striving to better meet customer demands and to improve the construction process as well as its product (Howell 1999). Lean has proved to be a valuable philosophy for construction; Ballard and Howell (2004) and Emmitt *et al* (2005) report on successful implementations. However, positive experiences are mainly related to an application of Lean practices on complex construction projects through the use of methods such as the Last Planner System of production control (Ballard and Howell 2003). Typical Swedish housing projects do not experience this broad complexity; instead the main concern seems to be a lack of knowledge of the customer value generation process (Olofsson *et al* 2004, Björnfot and Sardén 2006, Höök 2006).

Based on empirical results from three Swedish multi-storey timber housing producers, Björnfot and Sardén (2006) identified the application of product based technical platforms, called *product offers*, as means for the producers to create stable production systems and supply chains for efficient management of customer value and improved profitability. For these producers, the *product offer* seems to represent a strategic change where the organization is gradually becoming Leaner and ready for an implementation of specific Lean practices. According to Green and May (2005) such an organizational change represents a first stage of Leanness. As such, a strategic change through *product offers* ties in well with the principles of Lean Thinking (Womack and Jones, 2003), i.e., the key is to specify customer value by specific products and then to never lose sight of this value as the value stream is reformed and none-value adding activities are removed.

The aim of this paper is to evaluate the potential of the *product offer* as a means of facilitating the delivery of value in housing construction. First, a basic understanding of value and value delivery through Lean Construction is provided after which the *product offer* is defined through experiences from Swedish timber housing construction emphasized by volume prefabrication. Through the principles of Lean Thinking the *product offer* is then argued as a strategic application of Lean Construction which aids in the generation of internal (own) and external (customer) value. Finally, empirical results from a fresh Swedish development initiative in multi-storey timber housing construction are presented that provides a deeper understanding of how value is delivered through *product offers*.

The nature of value in Lean Construction

The concept of value

In traditional housing construction projects it is common to initiate the design process using a vague conceptualization of the end structure which leads to an inefficient design process where extensive customer involvement only increases complexity (Bertelsen and Emmitt 2005), i.e., design changes become a frequent occurrence as the perception of value for the client changes. An additional effect of the fragmented construction process is waste during the production phase which in Swedish housing accounts for up to 35% of the production costs (Josephson and Saukkoriipi 2005) and adverse participant relations (Sardén 2005) leading to even more waste in a business perspective as prices are continuously negotiated. It seems that a lack of consideration for the value generation process can have dire consequences for all project stakeholders.

Value, as defined in *Lean Thinking* (Womack and Jones 2003), refers to materials, parts or products – something materialistic which is possible to understand and to specify (Koskela 2004). Construction is a process of delivering this value to the client through a temporary production system (Bertelsen and Emmitt 2005). The client is often an organization representing owners, users and society who values different things at different times during the life of the building, e.g., durability, usefulness, beauty, flexibility, environmental aspects, etc. (Bertelsen & Emmit 2005). The other construction team members also have values to fulfil, but their main concern should be to deliver the best possible value to the client whom otherwise would look elsewhere (Emmitt *et al* 2005).

Value may be divided into external and internal value (Emmitt *et al* 2005) – external value is the clients' value and the value which the project should end up with, while internal value is the value that is generated by and between the participants of the project delivery team (contractor, architects, designers etc.). In this paper internal value is synonymous with profitability and independence (Cuperus and Napolitano 2005). Independence provides stakeholders with increased control over the internal value generation process through the shielding of their production systems from external sources of variety, such as late unforeseen design changes.

Even though the project delivery team tries very hard to design and produce a product to suit the specific wishes of the customer, the result of this value generation process is often a building different from the initial customer conceptualization. It seems that the way value is currently generated in construction projects leads to increased complexity and commonly results in waste generation at the expense of providing value for stakeholders. As a result, project stakeholders inevitably end up salvaging as much as they can out of construction projects through claims (Sardén 2005).

Value delivery through Lean Construction

A fundamental aim of Lean Construction is to aid in the delivery of external value by managing the internal value generation process. To aid in internal value generation, the most commonly referred to Lean techniques in construction are work flow control through the Last Planner system (Ballard and Howell 2003), value stream mapping (Rother and Shook 2001, Arbulu and Tommelein 2002), just-in-time production and supply-chain management (Low and Mok 1999), and pokayoke or the five why's technique (Tsao *et al* 2004). Another development effort in Lean Construction is target costing which aims to decrease costs so that a required profit level can be assured (Granja *et al* 2005), i.e. an integrated internal/external value view.

Other interesting and increasingly popular development efforts aiding in the delivery of external value are improved planning tools such as Line-of-Balance (Kenley 2005) and computer-aided design using 4D CAD (Rischmoller *et al* 2006). Another Lean Construction advance is Lean Design (see e.g. Freire and Alarcón 2002) which makes late design changes possible. However, if changes are made too late in the process they may still contribute to waste, especially in stable production systems (Stehn and Bergström 2002).

In Lean Construction, the project is in itself considered a fundamental feature of construction and the production system is designed with the project as its core. In traditional construction projects, external value is generated in the design phase through negotiations. Even if there are no Lean Construction methods available to specify external value there are accepted methods which aid in the value generation process; examples of such methods are partnering and concurrent engineering (Cheng and Li 2004) with incentives for team work in design and the facilitation of value generation throughout the iterative design process.

Based on experiences from the implementation of Lean in manufacturing, Oliver *et al* (1996) conclude that Lean practices are effective at fine-tuning a system which is already basically under control - it seems that implementation of practices alone are not enough for Lean. Ideally, the development of Lean Construction theory and applications should include an understanding of the Lean Thinking principles (Value, Value stream, Flow, Pull and Perfection) advising producers on how their production systems should be transformed so that value can be maximized and waste minimized (Womack and Jones 2003). In terms of a Lean thinking, production should be aimed at satisfying customer value by specific products (external value), while value for project participants (internal value) should come from waste reduction activities and continuous improvements within value streams.

In construction there is still undoubtedly a large variety originating from poor process control and unforeseen and uncontrollable external factors such as weather and traffic. Swedish prefabrication initiatives are structurally changing the multi-storey housing industry towards a kind of manufacturing; one of the main strategies for the implementation of a Lean thinking in construction (Bertelsen 2004). A fundamental aspect of this transformation is the *product offer* which aids producers in the delivery of external value by stabilizing their internal value generation processes.

Value delivery through *product offers*

The large majority of Swedish producers of detached housing (single occupancy) have well developed production systems where the product (the house) is prefabricated and targeted at specific customers who enjoy great flexibility within the constraints of the production system, e.g., architectural and floor-plan customization are partly limited. As an example, the largest Swedish detached housing producer offer limited flexibility through a fixed set of options (much like a car manufacturer). Through these options their customers (private home owners) are provided a sense of great flexibility at a very competitive price. There are also detached housing producers who offer their customers more flexibility - their prices are generally higher due to a more complex product and production system. The detached housing producers have realized that specialization is a condition for profitability and ultimately survival and that it is very difficult to be profitable by approaching the requirements of every possible customer. As such, these producers pursuit of value delivery for specific customers is similar to companies within the manufacturing industry.

Even considering the long-term success of the detached housing producers, the Swedish multi-storey housing industry has been slow to adapt; the industry is still in an era of traditional production where construction companies generally compete for their customers with production systems suitable for numerous different customers. As a consequence, the construction process is prone to waste generation for both customers and construction process participants (Björnfot and Sardén 2006). Furthermore, Josephson and Saukkoriipi (2005) argued that construction companies who try to be best at everything by pursuing every possible project create further waste since much resource are spent without any result in extensive and frequently unsuccessful bidding competitions.

Volume prefabrication – an example of a *product offer*!

In the Swedish multi-storey timber housing market, there are a number of small- to mid-sized producers who have realized that it is possible to gain benefits from specialization. A key aspect of this specialization trend is a clear identification of the customer and the development of a technical platform, a *product offer* (similar to detached housing) based on the values of the targeted customers. As such, the *product offer* is a well-defined and highly standardized building system (including design, manufacturing, assembly, and supporting services such as long-term quality assurance, financial aid, etc.) allowing for the design of a stable and efficient long-term production system. To understand the *product offer* as an *alternative* Lean Construction strategy for value delivery in multi-storey housing construction, volume prefabrication is used to further define its core characteristics.

The volumes are produced in a standardized manufacturing process where wall and floor elements are assembled to three-dimensional volumes (see Olofsson *et al* 2004, Björnfot and Sardén 2006, Höök 2006). Before delivery to the construction site, the volumes are finished with installations, façade, interior surfaces and finishing forming ready-to-use living space. Value delivery for volume production (condensed from the literature cited above) is for each project performed through four parallel processes (project management, design management, purchasing and production) illustrated in Figure 1.

Figure 1: Schematic illustration of value delivery through volume prefabrication.

What drives these four processes is the volume system (a *product offer* as defined above) which is designed according to the requirements from the market. Adopting the *product offer* strategy has supported the volume producer in designing their production system:

- **Project management.** The case company prefer to, and most often, offer their standardized volume system to landlords through general long-term agreements that roughly specifies both client options and individual options for the client's customers – the tenants. Through these general agreements, customer value is adapted to the needs of individual clients. Adopting the *product offer* allows the volume producer to utilize a "simplified" tendering process that adapts the house layout to the project in question, negotiates price and date of delivery, and sets up a list of options for the clients' tenants. After initiating the manufacturing process, the production process is thoroughly managed for increased control and stability.

- **Design management.** The volume system is specifically adapted to the project in question by specifying for example individual tenant options and site characteristics for the current project. Often only minor changes of the principle design (interior and façade design, and add-ons such as balconies) are allowed to keep a high production-to-cost efficiency. When the contract has been signed, the client initiates the sales and customization process of the houses (certain individual options are even possible after manufacturing has been initiated). When 30% of the apartments are sold, the start order is given for detailed design to commence after which documentation is supplied to the manufacturing process.
- **Purchasing management.** Through the adoption of a long-term *product offer* the volume producer is in control of the whole value stream which consists of long-term general agreements with subcontractors (carpentry, electricity, ventilation, etc.) who are brought in-house to perform their work, with assembly teams for on-site construction and with suppliers for a stable long-term supply chain for reliable material deliveries. For each individual project, contracts are signed for the required resources. When manufacturing is initiated the volume producer is then able to call on the pre-purchased resource so that production can be performed smoothly and without delays.
- **Production management.** For each individual project, and based on the individual customer options, the volume production system is prepared to allow for manufacturing to begin. From the detailed design phase, design drawings are delivered to the manufacturing process. When manufacturing is initiated, information of selected customer options from the customization process is passed to the production process so that the individually customized tenant-owned purchased apartments can be manufactured. The manufacturing process uses automation in conjunction with traditional construction work to produce volumes in a cost-efficient manner with short lead times.

The *product offer*: an application of Lean principles?

The *product offer* strategy seems to be a new way of thinking, a Lean thinking, in the delivery of value for the multi-storey housing industry rather than an implementation of specific Lean practices. Garnett *et al* (1998) argued that delivering customer value means organising around a product and/or service which provides continuity and stability. The *product offer* strategy takes on this challenge by controlling the inherent variety of construction through continuity (long-term thinking) and stability (reduced production system variability). Understanding the *product offer* through the Lean Thinking principles promotes the adoption of the *product offer* as a strategic application of a Lean thinking for value delivery in multi-storey housing construction. Lean characteristics (as viewed from Swedish timber housing industry practices) introduced into the production system by producers adopting *product offers* are outlined in Table 1.

From Table 1, the *product offer* is specified and detailed from customer requirements (**Value**) but managing customer value through the *product offer* forces the customer to lock their options to a specific technical platform (building system) offered by the producer.

Locking customer options allows the producers to be in control of a stable value generation process where customers are allowed flexibility through selected add-ons and options such as façades, apartment layouts and interior finishing. Consequently, value is specified by specific product for specific customers, which enables stability.

Table 1: The Lean characteristics of the product offer

Lean principle	The product offer implies…
Value	…detailed product specifications developed from customer requirements captured on the market where the product is intended.
Value stream	…definition of the specific resources and activities required for supply chain management and product realization.
Flow	…control of a stable value stream so that value adding activities can be better managed and so that waste can be eliminated or reduced.
Pull	…flexibility and adaptability to current and future customer demands and the ability to find ways of reducing lead times.
Perfection	…stable and transparent processes and operations allowing for continuous improvements by experience feedback.

In production system design, the stability conferred by the *product offer* is discerned through the specification of activities and resources required for product realization (**Value stream**). Continuity provides a steady foundation (process stability) for continual improvement through identification and elimination of non-value adding activities (**Flow**) (Table 1). Working with *product offers* provides a foundation for successful supply chain management which is facilitated by lower variability in delivery (quality, time and amount) and continuity for suppliers who are provided with a stable base from which to facilitate their own profitability through improvement programs (**Perfection**). In a sense, a transparent production system where everyone can see everything and where everyone is working towards the same goal is both facilitated by and a requirement for a *product offer* strategy since stability and continuity cannot be reached without a stable supply chain.

If customization is of value to the customer then enough flexibility must be incorporated in the design of the *product offer* so that value is delivered (**Pull**). According to Naim and Barlow (2003), profitable customization requires a robust supply chain for changes in both product volume and product variety. Ensuring enough flexibility is a continuous struggle for housing producers relying on prefabrication strategies (Stehn and Bergström 2002) since the customers' perception of value does change over time. Hence, the *product offer* must continuously be developed so it can be adapted to the changing market (Table 1).

To conclude, an adoption of the *product offer* strategy provides construction practitioner with Lean characteristics throughout their production system; its stability creates a stable value stream which results in a stable production system with activities which can be continuously improved upon so that flow can be established and internal value updated.

Specification of value through *product offers*

Looking back at the volume prefabrication example it can be argued that as a result of working with *product offers* Lean characteristics (Table 1) can be observed throughout the volume producer's production system. Examples include:

- a stable and continuous value stream and supply chain,
- a well developed manufacturing and site assembly process,
- customer pull through flexibility and adaptability and
- a shared process design with suppliers and academics to facilitate improvements.

However, the volume producer can still not be considered Lean since no specific Lean Manufacturing practices, such as visual control or work smoothing, can be discerned in their everyday work. But it seems that the stability and continuity incurred by the *product offer* presents a good opportunity to implement these Lean practices.

Experiences from volume prefabrication provide insights into successful *product offer* design. Successful development of a *product offer* requires clear specification of the product and associated services (**product specification**) that are related to customer requirements so that the value asked for is what is produced and delivered. Consequently, close relations with current and future customers (**external relations**) are important so that the product offered can be adapted to changes in what customers want. To facilitate work in a changing market, stability within the production system is required (**internal relations**) as well as control over the delivery from external suppliers (**supply chain management**). In the next section, empirical data from a Swedish initiative at *product offer* development is provided. In this initiative, the above mentioned aspects are used to describe how value is specified during a *product offer* development effort.

A Swedish *product offer* development initiative

The initiative reported on involves three Swedish timber component producers and one firm of architects. The volume producer described in relation to Figure 1 is part of this initiative. The aim is to increase the producers' share of the multi-storey housing market. As of now, the *product offer* has not been seen in practice, yet a discussion of how the *product offer* has been developed is of interest to deepen the understanding of its application as a Lean strategy for housing construction. The presented results are based on data collected over a one year period including interviews with managers and production personnel, participation at design meetings and documentation relating to the initiative.

Product offer development & specification

The competitive edge of the developed product was initially stated as offering a "complete package" (from design to assembly) in a cost- and time-efficient industrialized construction process involving the main products of the involved companies; prefabricated timber elements and volumes (Figure 2). The companies all have high expectations of the outcome of the initiative; the volume producer achieves improved flexibility in their *product offer* enabling consideration of new client values while still producing a familiar product. The element producer whose prefabricated element system (Björnfot and Stehn 2005) is lacking in development would gain an increased share of the housing market and the possibility of developing their element system in real applications. As the architectural values of customers change, the long-term involvement of the architect ensures that new architectural forms and layouts can be developed that specifically support the *product offer* without compromising the producers manufacturing processes.

The main customer for the *product offer* was identified as landlords who offer flats to tenants at a price of around 110 €/m^2 (living area) in multiple floors. The calculated total cost for a regular sized apartment was 1300 €/m^2 (compared to about 1700 €/m^2 per apartment in traditional housing construction). Based on these costs a target *production cost* of 800 €/m^2 was agreed for the development of the *product offer*. The layout of the houses is based on volumes but to achieve a higher degree of layout flexibility than can be accomplished with volumes alone prefabricated timber elements are used. The main idea was to use both volumes and elements where they are best suited. A large and difficult part of on-site production was identified as finishing off "wet areas" such as bathrooms and kitchens. Therefore, it was decided to attempt to prefabricate such areas as volumes and to include as much as possible of the installations since experience has shown that site production of installations is a common source of waste and that higher quality can be maintained inside factories.

Figure 2: The <u>product offer</u> integrating prefabricated timber volumes and elements.

During design development, wall and floor elements were standardized to simplify the manufacturing and site assembly processes. This effort significantly reduced the number of elements used. Standardization was considered an important aspect in promoting a construction process where standard work in manufacturing, delivery and site assembly could be utilized. Surprisingly, it was not until late in the process that standardization became a key aspect. By the end of the development process, a production cost of 900 €/m^2 was achieved which was higher than the targeted cost. However, the delivery team is continuously looking to improve the *product offer* so that the target cost can be achieved.

Relations & supply chain management

Through the *product offer*, the producers are able to use a simplified tendering process similar to the practice already used by the volume supplier (see Figure 1). The simplified tendering process involves relational contracting among the producers so that the customer does business with one delivery team instead of a multitude of independent subcontractors. The main customers for the *product offer* are landlords but the improved flexibility makes the *product offer* attractive to contractors as well. The increased flexibility of the product offer also enables clients to become further involved in the design process without compromising the stability and continuity of the producers manufacturing processes.

The standardization effort resulted in reduced production costs due to cost and time savings in manufacturing and assembly. This allowed the delivery team to pinpoint key component suppliers and to simplify the supply chain by reducing the number of suppliers, i.e. it was decided on the suppliers who would be able to deliver required components when needed and at the right price and quality. The delivery team has a desire to integrate lower tier component suppliers into their value chains and to engage in long-term relations with suppliers so that stable supply chains can be formed. The aim of this effort is to

- allow the delivery team to be in control of the whole supply chain and
- involve everyone in continuously improving the product and associated processes.

A goal was to develop an on-site assembly process with manufacturing characteristics, i.e. use of automation for material handling and movement. Additionally, a dry site production process was aimed at through the use of a covering tent. Through this effort, the construction site becomes much like a factory in which components are shipped in and assembled as they are delivered. Such an assembly process demands attention on logistics for Just-in-Time delivery of components. To facilitate cooperation within the delivery team and control of the production system, a computer support system is being developed. The aim of the computer system is to

- allow for simultaneous sharing of information between the involved producers to aid in the design process,
- facilitate short lead times with increased customer involvement,
- support the manufacturing processes and
- guide the delivery of components to manufacturing and to the construction site.

Concluding case study remarks

Deciding on a course of action, in this case the combination of elements and volumes provides with stability and continuity – the variety of construction is integrated into the *product offer* which provides with a stable foundation for client negotiations, design development, production system design and continuous improvements of both the product and associated processes. Most of the development efforts in support of the *product offer* either enables Lean practices or are influenced by them, i.e.

- the *product offer* is highly standardized to facilitate *standard work* in manufacturing and assembly,
- internal relations are managed through *target costing* and *relational contracting*,
- external relations are managed through *flexibility* and
- the supply chain is managed through l*ong term supplier relations* to enable *continuous improvements*.

Multiple similar endeavours to this case are currently being developed in Sweden characterised by a stable *product offer* acting as a driving force for improvements - it seems as if the *product offer* strategy provides an initial stimulus towards a Lean thinking in multi-storey housing construction.

Discussion

The aim of this paper was to evaluate the potential of the *product offer* (a well-defined and highly standardized building system developed from the value views of specific customers) as a strategic application of Lean to facilitate the delivery of value in multi-storey timber housing construction. It was argued that producers who adopt *product offers* approaches Lean Construction on a strategic level; it is a new way of thinking about the delivery of value for the multi-storey housing industry, rather than an implementation of specific Lean practices. Based on the principles of Lean Thinking it was argued that the application of the *product offer* is a Lean strategy for value management. Case study experiences indicate that the *product offer*, through its stability and continuity, provides with Lean practices in marketing, design and manufacturing.

It should be noted that there are critics against the understanding of construction through the principles of Lean Thinking. For example, Koskela (2004) argues that the principles are insufficient for the task of changing construction to Lean. However, this research indicates that the principles can indeed promote a change of perception of production in multi-storey housing construction, particularly of how value is delivered and improved upon. In Lean Thinking, customer value (delivered as a product and/or service) is clearly of primary concern and governs the transformation of the production process so that value can be delivered as efficiently as possible. Since value delivery is what fundamentally drives the development and the use of the *product offer*, this paper proposes that the *product offer* should be considered as an application of a Lean thinking for construction.

Developing a *product offer* requires input from many specialized subcontractors who are often acting independently – they must work together towards a common goal instead of "minding their own business". The *product offer* development initiative described in this paper is an example of teamwork over organizational borders through relational contracting. Relational contracting provides stakeholders with incentives to make their best effort for the project, to use innovative thinking and to continuously improve on their own work (Matthews and Howell 2005). The case study experiences showed that it is possible to work together and deliver value in new ways by breaking the restraining influence of the traditional project oriented construction process.

The view on value differs between industries and even cultures. Therefore, the application of Lean will be different. A contractor of complex industrial projects may for example want improved control of site production through Last Planner while a producer may want manufacturing process improvements through practices such as the *Toyota Way* (Liker 2003). The similarity of these efforts is a new way of thinking, Lean thinking. Approaching Lean, small to medium sized Swedish suppliers should primarily focus on improvements through Lean Manufacturing. However, an emerging demand from Swedish contractors forces these suppliers to take larger responsibility in the construction process. In this regard, the *product offer* is considered a Lean strategy for Swedish producers that, if fully developed and correctly applied, enable them to satisfy external value while being able to pursue profitability through stable production systems and supply chains.

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A Lean Modeling Protocol for Evaluating Green Project Delivery

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Abstract

The first vital step to leaning an operation is to model or map the processes used to deliver value in that operation. This allows the requisite understanding of where waste and non value-adding activity exists, and provides the foundation for improvement. Current protocols for modeling operations present the basic tenets for lean mapping, but tend to be based in manufacturing language, and are not easily adapted to capital facilities projects.

"Green" or "sustainable" capital projects delivered using current project delivery systems seem to be laden with hidden waste. These projects tend to be more challenging to deliver due increased levels of building system integration, untraditional materials, and requirements such as recycling, total commissioning, and increased project documentation. Penn State's Lean and Green Research Initiative has examined the delivery of multi-million dollar green building projects for clients including the Pentagon, Toyota, and Penn State's Office of Physical Plant. The processes used to complete these projects are difficult to model with current lean techniques.

This paper outlines a detailed modeling protocol for evaluating the delivery processes of green projects. Blending existing protocols and the specific needs of green building projects, this protocol will help define the data collection and analysis procedures, as well as the instruments (metrics) of analysis.

Keywords: Lean mapping, project delivery, green building, process modeling

Introduction

High performance "green" or "sustainable" buildings have the potential to reduce the environmental and economic footprint of the built environment by minimizing energy use, reducing resource consumption and waste, and providing healthy and productive environments for occupants. This is vital given that buildings consume 36% of total energy use, 30% raw material use, and 12% of potable water in the U.S. (Roodman and Jensen 1995; U.S. EPA 2004). The penetration of the U.S. building construction market by green building is already significant, valued at over $3.3 billion in 2004, and expected to reach $10-20 billion by 2010 (McGraw Hill Editors 2005). However, this

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figure represents less than one percent of the total non-residential building market in the U.S. There is also room for growth in developing countries such as China, where the rapidly expanding $300 billion a year construction industry currently gives almost no consideration to green building (Boardman 2005).

Yet little is known about the best processes to deliver green buildings. The greatest barrier to more widespread application of green buildings is the perception of their higher first costs (BDC Editors 2004). Research is beginning to show that delivery process features are a major factor in the increase of first cost for green buildings (Mogge 2004), and that owners modifying the traditional project delivery process to accommodate green buildings can reduce or eliminate their first cost increase for green buildings (Lapinski 2005). The building community should begin to understand the differences between traditional and green project delivery.

Lean principles can help develop a better understanding of the entire green building delivery process (i.e., from programming, planning, procurement, through design and construction to occupancy) and the cost impacts associated with this process. This paper describes the Lean and Green (L&G) protocol developed to facilitate modeling of the green building delivery process. Currently, there are no adequately defined models representing the delivery of green buildings. As a result, owners and professionals undertaking green buildings must deliver them based on their personal experiences rather than a set of standard principles. While this individualized approach can be successful in certain situations, there are problems associated with an undefined approach, the most important of which are difficulty in learning, testing, verifying, and teaching about the best processes to deliver green buildings. These difficulties are reduced or eliminated by a structured modeling approach, which also reduces instances where individual experiences are applied incorrectly to new or different situations (Alarcón 1997).

Objectives

The objectives for this paper are to explain the development of the L&G modeling protocol and provide a template for its application. The protocol will deepen understanding of the best processes to deliver green buildings and enable information sharing across lean and green communities through a standard modeling protocol. When adopted by researchers and practitioners working with building delivery processes, the model will have a very broad impact.

Background

Green Building

As world population and production expand, it is critical that sustainable approaches to energy consumption, greenhouse gas emissions, and water use are developed and implemented. The green building movement is addressing these issues through efficiencies and innovations in building design, construction, and operation. Multiple definitions for green building exist, and these definitions are frequently updated. However, prominent definitions generally include the fundamental principles describing green buildings, which are synthesized in the Whole Building Design Guide and form the definition of green buildings used in this paper (NIBS 2006). Green buildings are those which:

- Optimize site potential (reduce impact on ecosystems, required transportation, and energy use through considerations of location, orientation, and landscaping),

- Optimize energy use (reduce loads, increase efficiency, and consider renewable energy),
- Protect and conserve water (minimize runoff, use efficiently, and consider reuse),
- Use environmentally preferable products (materials which have reduced impact on human health and environment when compared to equally performing materials),
- Enhance indoor environmental quality (maximize day-lighting and views, control moisture and ventilation, and minimize volatile organic compounds (VOCs)), and,
- Optimize operational and maintenance practices (take measures to minimize the environmental impacts of building maintenance and to ensure the building will operate as intended).

High performance green buildings pay particular attention to energy efficiency and indoor environment quality (Horman et al. 2006). High performance buildings are the main focus of the modeling protocol described in this paper, although the protocol could be used on other green buildings as well.

Need for Systematic Modeling of Green Project Delivery

The optimal delivery processes for green buildings are not the same as those for traditional buildings. To achieve their performance benefits, green projects use intense interdisciplinary collaboration during design, highly complex modeling and analysis, and careful material and system selection particularly early in the project delivery process (Riley et al. 2004). Locally manufactured, often untraditional, and higher priced materials can be required for construction; and if certification--such as that under the U.S. Green Building Council's Leadership in Energy and Environmental Design--is sought, extensive documentation adds time and cost to the project.

The growing literature on green building offers many ideas to create green building features, but few methods for "where" and "how" green strategies should be implemented, or whether the recommended strategies will prove successful. Green requirements often incur an up-front or first cost premium (U.S. GSA 2004). This up-front cost is used to purchase better quality building components like HVAC systems and super-insulated building envelopes; "investments" that can achieve significant operational savings that extend over the life of the building.

Further adding to the upfront cost of green buildings, many green project processes are laden with wasteful rework, delays, changes, and overproduction as a result of not using the best delivery methods for these projects. Process waste can both undermine the achievement of sustainable outcomes and limit the business case for sustainability (U.S. GSA 2004; Lapinski et al. 2006).

Modeling is the critical first step to better understand green delivery processes. If process waste is trimmed from green delivery then sustainable outcomes can be enhanced without the current high first cost. For modeling to be effective, it must consider the unique attributes of the process it is representing, and a process modeling methodology for the green building delivery process should consistently represent the characteristics of green delivery processes. The Lean and Green (L&G) process modeling protocol provides a simple but rigorous methodology that conveys the complicated green building delivery process in a simple, effective style.

Modeling Protocols

Process modeling was popularized in the development of software to: (1.) Facilitate human understanding and communication; (2.) support process improvement; (3.) support process management; (4.) automate process guidance; and, (5.) automate execution support (Curtis et al. 1992).

The application of process modeling was expanded with the realization that these contributions to software development could also be beneficial to business processes. Numerous methodologies have been employed to model various business processes and interested readers are encouraged to consult Curtis's "Process Modeling" (1992) for a more detailed review of these methodologies. It is important that the L&G modeling protocol have a firm foundation in proven modeling sciences and existing methodologies are combined and supplemented to form of the L&G modeling protocol.

Modeling influences contributing directly to the L&G protocol are listed in Table 1 along with a brief description. The source references listed in the descriptions can be consulted for additional information. Each modeling influence listed in Table 1 is required to satisfy the expectations developed for the L&G protocol (Table 2).

Lean and Green Modeling Protocol

Goals and Requirements

The goal for the L&G protocol is to enable representation (current state maps), analysis, and improvement (future state maps) of the green building delivery process. This goal will be accomplished through incorporation of lean principles including:

- **facilitation of visualization and process transparency** (L&G models display processes in a format easily understood by those outside the building industry),
- **display of value adding activities** (L&G models incorporate the voice of the customer to identify value, then display processes that contribute to customer value),
- **display of wasteful activities** (Processes in L&G models not contributing to customer value are wasteful),
- **use of relevant metrics for process control** (L&G models help with metric application by clearly defining the process for measurement), and
- **analysis for optimized placement of added processes** (By defining the process, L&G models enable scientific evaluation of the best location for adding activities – energy modeling for example - essential to green building delivery.)

The associated targeted result of the L&G protocol is a straightforward, intuitive representation of the green building delivery process for application by researchers and industry professionals to compare, analyze, and improve green building delivery processes.

Table 1: Modeling Influences

Influence	Description
Integrated DEFinition method 0 (IDEF0)	A series of diagrams first showing processes at a high level and then decomposing them down to a series of sub-processes (Sanvido 1990)
Integrated Building Process Model (IBPM)	Applies the IDEF0 methodology in outlining the primary activities required to deliver a building (Sanvido 1990)
Flowchart	A graphic representation, using symbols and connectors, of a process (Damelio 1996)
Value Stream Mapping (VSM)	A process mapping tool, based on the concept of lean, focusing on a total process perspective and elimination of waste in manufacturing processes (Hines 2000)
Value Stream Mapping for Product Development (VSMPD)	A process mapping tool that adapts VSM for application to production processes (Morgan 2002)
Production Model	A process model that considers the differences between manufacturing and construction processes (Koskela 1992)
US NAVal FACilities engineering command (NAVFAC)	Process mapping applied to investigate NAVFAC’s green building delivery process (Sanders 2003)
Toyota Real Estate and Facilities (RE&F)	Process mapping applied to investigate RE&F’s green building delivery process (Lapinski 2005)
Salford	A generic process sequence for delivering sustainable facilities (Salford 2002)
Swimlanes	Horizontal lines added to process maps that enable representation of which group performs each task (Cordes 1998)
Information Sheets	Detailed written descriptions of an activity in a process map (Pojasek 2004)

Value Criteria Selection

Critical to the L&G modeling protocol is development of an understanding of what adds value for the customer. The final customers in green building delivery are the owner and end-users of the building. Lean theory defines value creation as providing for the customer the right product and/or service, at the right time, with the right cost (Womack and Jones 2003). Based on lean theory, value creation for the building end-user involves obtaining the building they specified, on time, and at the least possible cost.

The L&G protocol will apply “Voice of the Customer” (VOC) as a tool to help define end-user value. VOC complements lean theory, soliciting customer input to determine exactly what the customer’s needs are, and then using this input in product design. VOC is determined through either reactive (formal and informal complaints) or proactive (interviews, surveys and focus groups) measures (George 2003). After the VOC is determined, the L&G protocol will apply Quality Function Deployment (QFD) to translate needs identified through VOC into technical requirements for green building delivery.

Typically, costs associated with financial and manufactured resources are considered in value analysis. However, the L&G protocol also considers customer value associated with human and natural resources. In particular, the L&G protocol considers financial, manufactured, human, and natural resources in value determination concerning the environment. There is value to the building end-user in the generation and preservation of each of these resource types and there is waste in activity that absorbs these resources without providing value in return.

Table 2: L&G Modeling Expectations and Influences

	Modeling Influences → / Modeling Requirements	**IDEF0 Foundation**	IDEF0	IBPM	Flowchart	**VSM Foundation**	VSM	VSMPD	Production Model	**Green Building Delivery**	NAVFAC	RE&F	Salford	**General**	Swimlanes	Info Sheets	Green
	Technical merit																
T1	Is easily integrated			●													
T2	Has sufficient breadth		○	●			○		-								
T3	Has sufficient depth		○	●	○		-	-	○							○	
T4	Is decomposable		●	○													
T5	Is modular		●	○													
T6	Is extendable						○	○							●		
T7	Is quantifiable						○	○	○								
T8	Considers all value types											○					●
	Ease of use																
E1	Follows simple modeling rules		○	○	●		○	○	○								
E2	Is supported by computer tool																
E3	Is easy to follow, clear		-	-			○	○				●	○				
E4	Minimizes mapping time				○		●	○									
E5	Demonstrates process flow						●	○	○			○	-				
E6	Differentiates value and waste		-	-			●	○	○			○					
	Suitability for owners																
S1	Represents entire delivery			●			○	○				○	○				
S2	Represents all orgs. projects			○			○	○				●	○				
S3	Is specific to green building							○	○			●	○				○
S4	Increases process transparency						○	○				●	○				
S5	Is flexible		-	-	○		○	○	●							○	
S6	Considers the audience				○							●	○				
	Perspectives																
P1	Behavioral						●	○				○					
P2	Organizational (internal)											○	●				
P3	Organizational (external)														●		
P4	Informational															●	
P5	Functional		●	○	○		○	○				○	○				

Key
- ● Primary satisfier
- ○ Satisfies, not primary
- \- Does not satisfy
- Blank Cell N/A

Relation to Existing Models

To satisfy the goal and achieve the targeted result of the L&G protocol, modeling expectations were developed and categorized within; (T) Technical merit, (E) Ease of use, (S) Suitability for owner organizations delivering green buildings, or (P) demonstration of required Perspectives. Table 2 lists these expectations in the two left columns. For example, expectation T1 requires that models created by the L&G protocol can easily integrate with other models created by the same protocol. Satisfying this expectation will allow the combination of modeling from multiple organizations to create a single model representative of the green building delivery process.

To test for internal validity of the L&G modeling protocol, it was evaluated whether the protocol satisfies the expectations specific to the L&G research initiative. The matrix section of Table 2 demonstrates how each L&G modeling expectation is satisfied by at least one modeling influence. For example, we see that the IBPM influence is the primary satisfier of expectations T1 (is easily integrated), T2 (has sufficient breadth), T3 (has sufficient depth), and S1 (represents the entire delivery process.) However, the IBPM alone cannot satisfy all of the expectations of the L&G protocol and the VSM influence is the primary satisfier of expectations E4 (minimizes mapping time), E5 (demonstrates process flow), E6 (differentiates between value and waste), and P1 (demonstration of behavioral perspective.)

While Table 2 shows how the L&G protocol influences contribute to L&G mapping, Figure 1 demonstrates the relationships between the influences. IDEF0 and Value-Stream Mapping (VSM) form the foundation for the protocol. The IDEF0 methodology is a series of diagrams first showing processes at a high level and then decomposing them into a series of sub-processes. VSM is a mapping methodology based on lean principles that originated in manufacturing and demonstrates total process flow while enabling identification of value and waste.

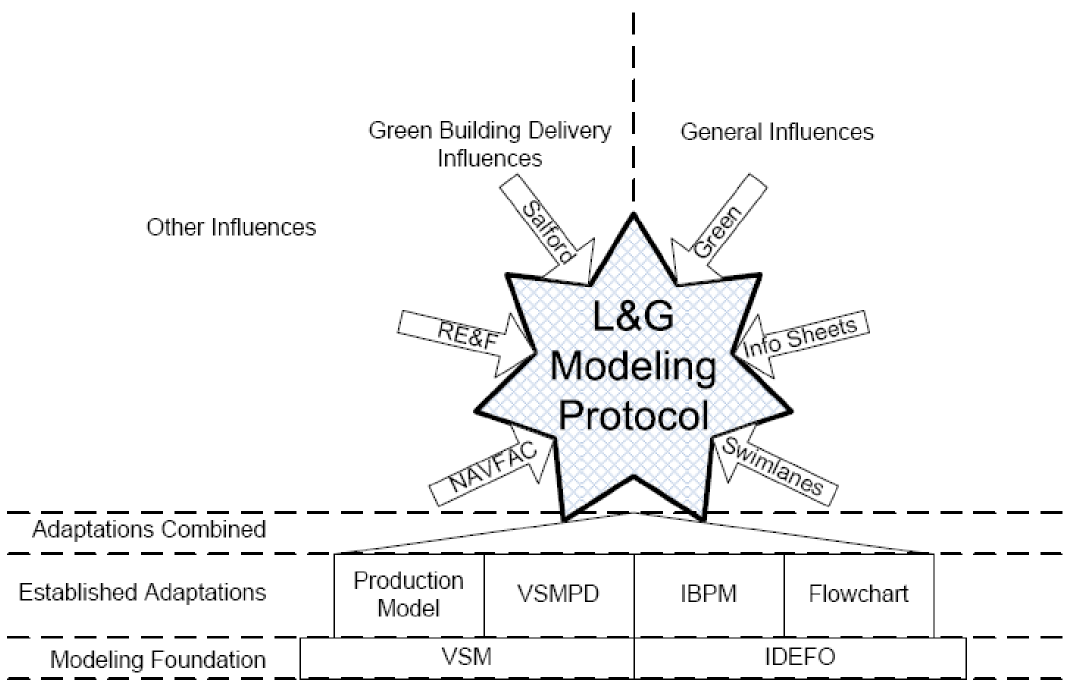

Figure 1: L&G Modeling Influence Relations

Directly above VSM and IDEF0 in Figure 1 are: Flowcharting; the Integrated Building Process Model (IBPM); Value Stream Mapping for Product Development (VSMPD); the Production Model; and Phase Scheduling. Flowcharting provides a simple, detailed capability to the L&G protocol. The IBPM is an adaptation of IDEF0, representing all of the tasks required to deliver a building (Sanvido 1990). VSMPD is an adaptation of VSM that is appropriate for product development (Morgan 2002), which is more similar to building delivery processes. The Production Model further adapts VSM, addressing the differences between manufacturing and construction processes (Koskela 1992). Combined, these adaptations provide the primary influence for the L&G protocol.

The remaining influences for the L&G protocol are divided into general influences and green building delivery influences. Because of the lack of relevant published research, green building delivery influences on the L&G protocol are limited to research done at the University of Salford, at Toyota Real Estate and Facilities (RE&F,) and at Naval Facilities Command (NAVFAC.) Research at Salford produced a series of process sequences illustrating the phases that may be undertaken during green building delivery (Salford 2002). At Toyota RE&F, Penn State researchers mapped the delivery process, examining how Toyota delivers green buildings with no additional first cost to the project (Lapinski 2005). Penn State researchers at NAVFAC applied process modeling in an effort to provide recommendations on how to incorporate sustainability into the Naval facilities acquisition process (Sanders 2003). General influences include:

- Swimlanes, which are horizontal lanes added to the model representing the organization responsible for each process (swimlanes are borrowed from deployment flowcharting, developed by W. Edwards Deming, and popularized in the U.S. by his disciple Myron Tribus (Cordes 1998)),
- Information accounting sheets describing each sub-process activity in detail (Pojasek 2004), and,
- Green influences, described in more detail in the next section.

Green Influences

Requirement T8 of the L&G protocol is recognition of all types of value and waste in terms of human, financial, manufactured, and natural resources. This ability is crucial to obtain an accurate measure of value and waste for any process, and is especially important in analyzing processes, like green building delivery, with green products. To accurately assess value and waste, value must be assigned to natural resources (living systems) and human resources (social and cultural systems) that are the basis of human existence (Hawken et al. 1999). If all resource types are not considered, delivery factors that may impact the environmental, or “green” values to the customer (e.g., environmental burdens in operation, service life, risk of deterioration, convertibility, and flexibility) are overlooked. To emphasize this point, Table 3 provides examples of value and waste, specific to green building delivery, in each of the four resource types.

Previous green building mapping efforts added the environment as a customer to account for needs specific to green building delivery (Lapinski 2005). Now, in the L&G protocol, all of the environment’s needs are expressed through the natural and human resources needs of the building users. For example, reduced greenhouse gas emissions resulting from decreased energy use are now considered as a natural resource need for the building user rather than a requisite of “the environment.” This change clarifies the link between users and natural resources and, by limiting the number of customers, streamlines the mapping effort.

Modeling Components

L&G modeling begins with development of the macro level process overview (level 1 mapping) and continues with micro levels (levels 2 and 3 mapping) in increasing amounts of detail. Level 1 mapping displays a value-stream perspective of the overall green building delivery process. This prevents a common problem in mapping exercises where sub-processes are optimized locally at the expense of the overall system performance (Arbulu and Tommelein 2003). For each macro-level process, a level 2 map is developed showing the associated sub-processes. At the top of each level 2 map, a Reference Key enables the reader to maintain a big-picture understanding of the map location in the overall delivery process.

Table 3: Green Influences on L&G Modeling Protocol

Resource	Examples	Value Example	Waste Example
Human	Labor, intelligence, culture, organization	Workshops educating occupants on the benefits of green buildings	Ignoring contractor's knowledge during building design.
Financial	Cash, investments, monetary instruments	Requiring cost estimates from multiple contractors.	Late identification of green goals - when they cost more to achieve.
Manufactured	Infrastructure, machines, factories	Constructing a building.	Demolition of a building suitable for renovation.
Natural	Living systems, ecosystem services	Energy modeling to reduce energy consumed.	Oversizing an HVAC system.

Icons

Icons used in L&G modeling are shown in Figures 2-3. The appearance of the icons needs to be easily understood by the organization using them. For example, many standard icons typically chosen for value stream mapping are based on a manufacturing environment and are not the best choice for use in a construction organization.

Rules

Rules for the L&G protocol are minimized for modeling simplicity and to reduce opportunities for modelers to inadvertently break these rules. L&G rules to guide map development are:

- a process must start with an input and have at least one activity and output,
- the output of one process must be the input of another process,
- an input must be succeeded by a process and cannot be succeeded by an output,
- a process must be succeeded by another process, a decision, or an output, and,
- an output must not be succeeded by another output.

Boundaries

Essential to any process modeling exercise is definition of the modeling boundaries (Tang et al. 2004). Definition is especially important in the modeling of building processes where significant inefficiencies occur around the boundaries of processes, disciplines, and organizations (Arbulu and Tommelein 2003, NIST Editors 2002). The structure of the L&G protocol enables modeling to continue through internal boundaries between levels, processes, departments, and organizations. The L&G protocol ends only at external boundaries, (prior to conception of a building and after the building's useful life).

Modeling Format – Data Collection and Display

To begin development of maps using the L&G protocol, modelers must first become familiar with the organization being modeled so that the value of time spent with members of the organization is maximized. Initial data collection can include observation from within the organization being modeled and must include review of applicable organizational procedure manuals, standard forms, meeting minutes, project records, and schedule templates. In the case of practitioners mapping processes within their own organization, this initial organizational study is unnecessary.

Level 1

After a basic understanding of the organization is achieved, the modeler can begin development of a Level 1 map. Interviews with an employee who understands the basics of an organization's overall delivery process, typically a high-level executive, are effective in developing the level 1 map. An initial two hour interview session is sufficient to provide information for development of a draft level 1 map, and a follow-up one hour session will clarify that the draft map represents the interviewees understanding of the overall delivery process. Figure 2 provides an example of data collected for a Level 1 map created for Penn State's Office of Physical Plant, while Figure 2A displays the resulting Level 1 map.

Questions to ask in the level 1 and level 2 mapping interview sessions are adopted from VSM due to its focus on understanding the overall system perspective. Hines and Taylor's (2000) general questions in their seminal work "Going Lean" focus on understanding customer requirements, information and physical flows, and links between these flows to create a big picture map. These questions can be tailored to green building delivery and combined with questions from the green delivery mapping at Toyota RE&F (Lapinski 2005). Modelers can also apply their familiarity with the organization to be mapped and their knowledge of lean mapping principles to develop questions suitable for their specific situation.

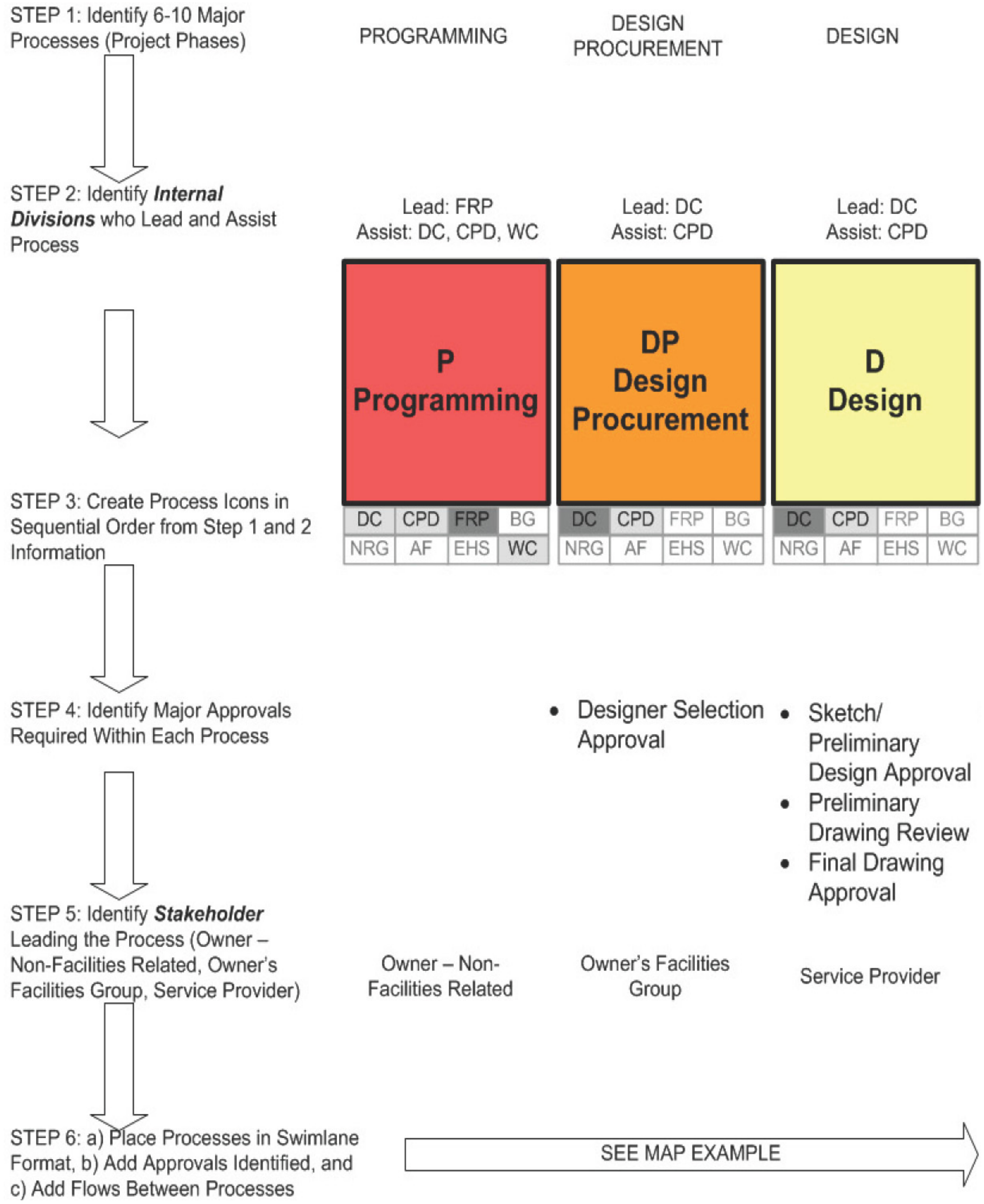

Figure 2: Level 1 Mapping Data Collection (For visual clarity, this figure represents only a section of OPP's delivery process. Complete maps are available from the author by request.)

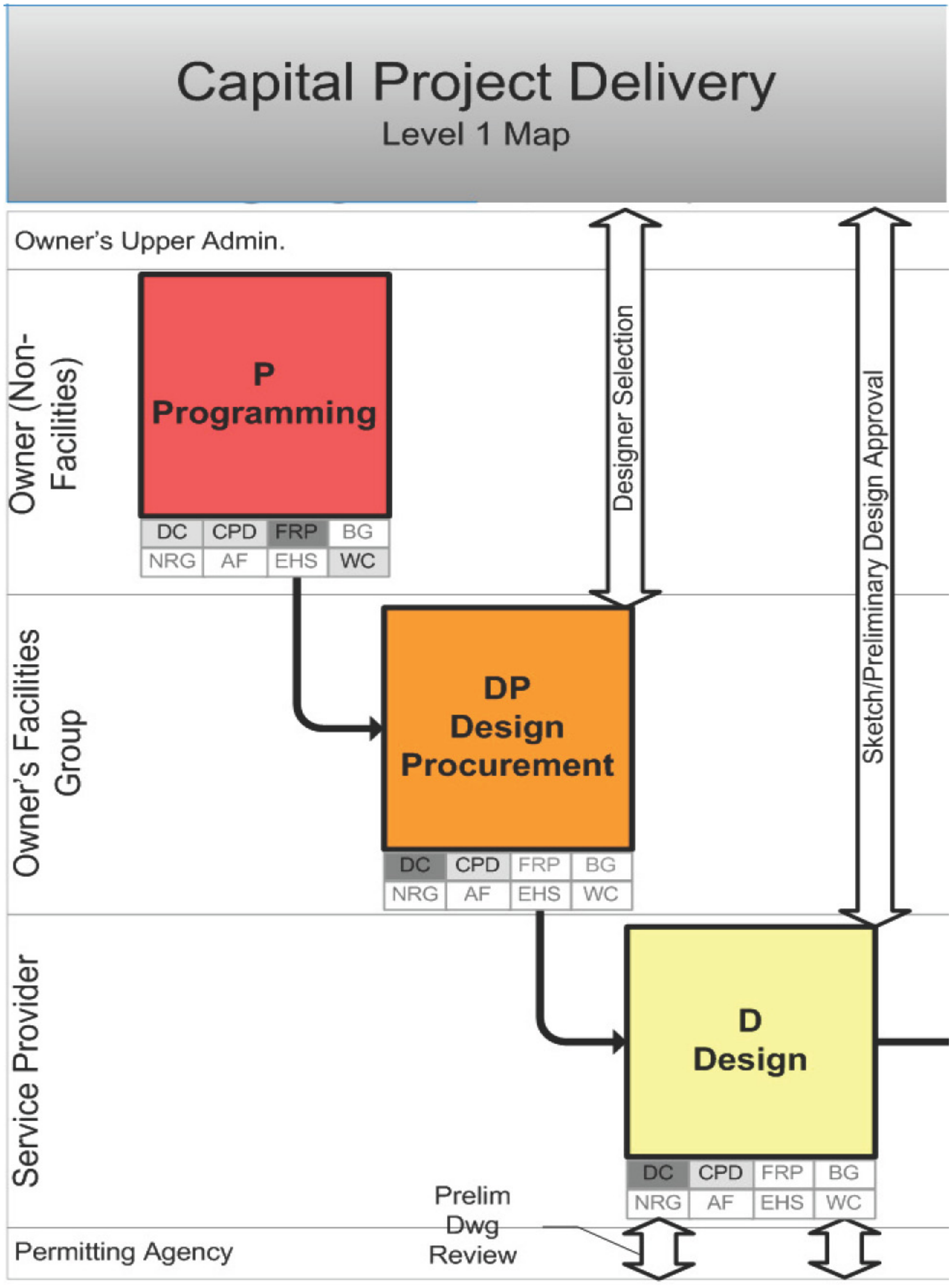

Figure 2A: Level 1 Map (For visual clarity, this map represents only a section of OPP's delivery process. Complete maps are available from the author by request.)

Level 2

At the end of the second level 1 mapping meeting, the modeler should work with the interviewee to identify an interview subject for each of the processes in the level 1 map. To obtain the most accurate maps, these interviewees are the members of the organization that best understand the applicable process. For example, it is likely that the organization members that best understand the programming or planning process are different from the members who best understand the construction process. With each of the level 2 interview subjects, the modeler should follow a similar procedure to that employed for the level 1 mapping, gathering information from an initial two hour meeting and a follow-up one hour meeting to complete a level 2 map. Figure 3 provides an example of data collected for a Level 2 map created for Penn State's Office of Physical Plant, while Figure 3A displays the resulting Level 2 map.

Level 3

To create detailed level 3 maps, it is no longer sufficient to rely exclusively on senior managers as we did in levels 1 and 2 mapping. The front line workers involved in the day to day operations of the sub-process being mapped must be consulted to get a complete picture of what actually happens in the process (Hines and Taylor 2000). To address this issue, multi-disciplinary teams are formed that are familiar with a specific sub-process being mapped. With the aid of these groups, maps for each sub-process are created and verified (Rother and Shook 1999). Data collected for and formatting of Level 3 maps follows the same procedure as outlined for Level 2 in Figures 3 and 3A.

Future Plans – Map Analysis

Developing process maps using the L&G protocol is the crucial first step in understanding and improving green building delivery. The map development process itself will likely have immediate benefits to organizations employing it, increasing understanding of their processes. However, the majority of expected benefits will be realized after completion of the initial mapping. Completed maps will provide "transparency" (a visual representation of the entire process) for all stakeholders in the delivery of green projects. This whole-process perspective is crucial, as stakeholders with a better understanding of the entire process, and their role within it can contribute to a more efficient process. More importantly, completed maps will allow analysis for potential changes aimed at making the process more effective. Steps deemed as wasteful or non value adding to green building delivery can be removed to streamline the process. Also, strategies recommended for delivering green buildings (ex. energy modeling) can be placed optimally within the process models and analyzed for value-added. Future-state process maps, where wasteful activities are removed and required strategies are added in their optimal location, will guide a more efficient and effective green building delivery process.

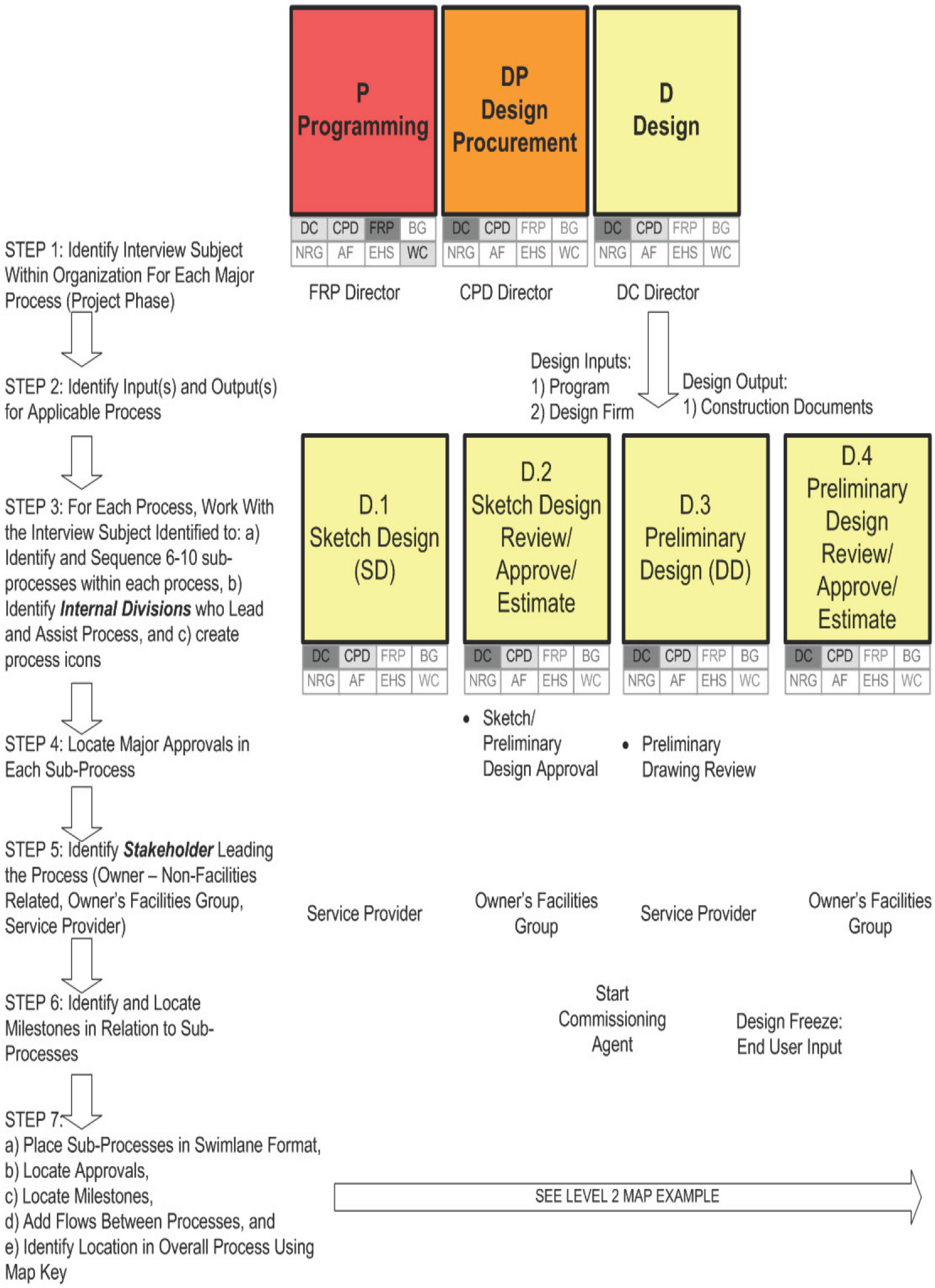

Figure 3: Level 2 Mapping Data Collection (For visual clarity, this figure represents only a section of OPP's design process. Complete maps are available from the author by request.)

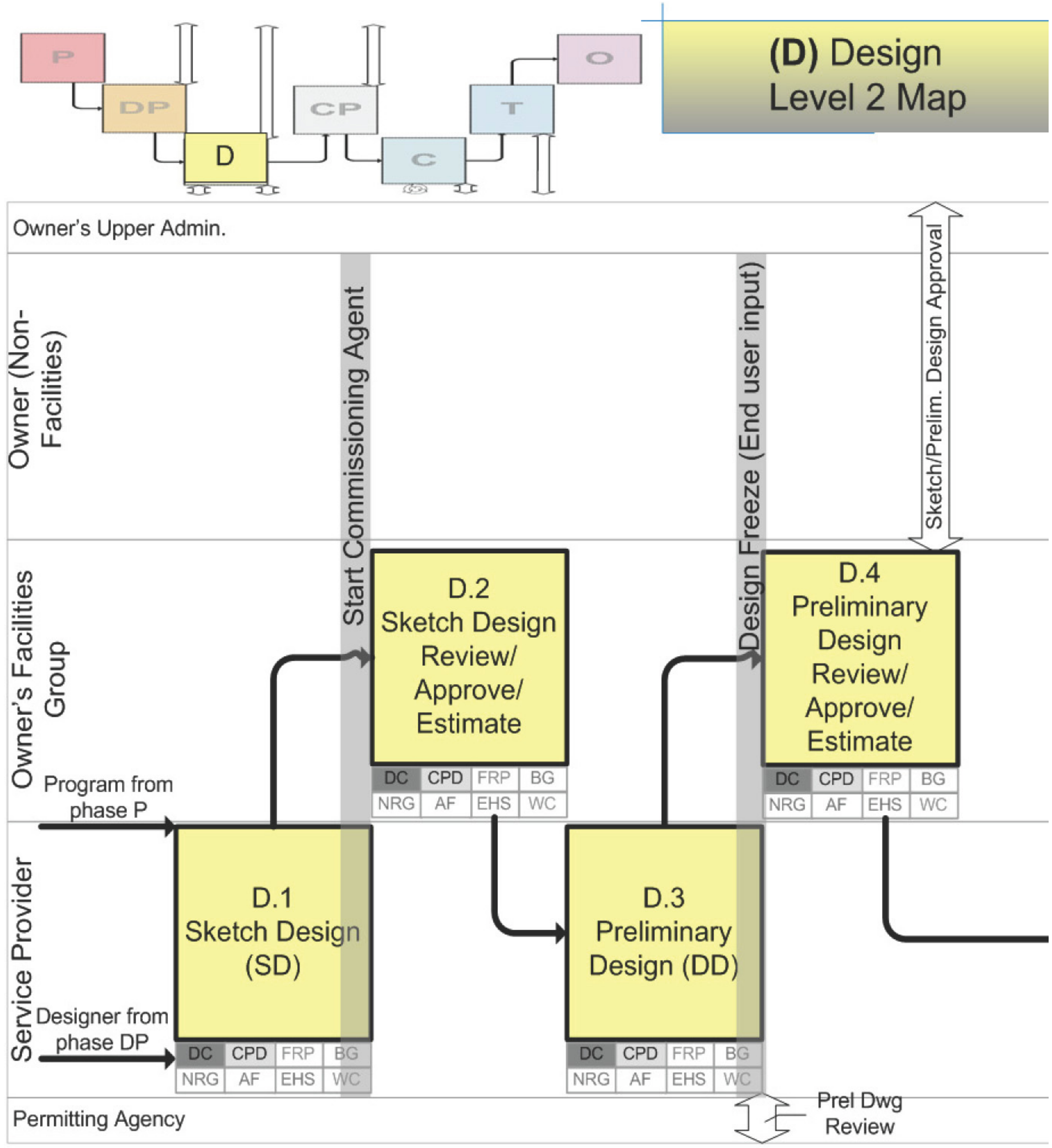

Figure 3A: Level 2 Map (For visual clarity, this map represents only a section of OPP's design process. Complete maps are available from the author by request.)

Limitations

All major parties involved in the delivery of green buildings are represented in the swimlanes of the L&G protocol maps. However, the mapping examples described in this paper are developed from an owner's perspective. In the future, testing of the L&G protocol will be expanded to include mapping from the perspective of architects, contractors, suppliers and other organizations in the supply chain of construction projects. Adding perspectives helps with comparison of tasks being performed by various groups to identify duplication of work, a problem that plagues building delivery (NIST Editors 2002). For example, a recognized inefficiency in green building delivery is in the transfer of information from the owner to the architect and from the architect to the contractor (Mogge 2004). It is a basic tenet of value stream mapping that customers and suppliers should be involved in the coordination of the supply chain to reduce this waste between companies (Jones and Womack 2002). In the building industry, extension of the value stream is recognized as a necessity due to the fragmented nature of the industry (Arbulu and Tommelein 2003).

Conclusions

The optimal processes to deliver "green" or "sustainable" capital projects are not the same as those for conventional buildings. Green projects tend to be more challenging to deliver due to the unusual and non-traditional requirements of green buildings. Using conventional delivery methods results in process waste on green projects that reduces levels of sustainability and unnecessarily increases project costs.

In order to understand how best to deliver green buildings, this paper outlined a modeling protocol. The development of this modeling protocol attests to the maturation of lean practices in construction. As lean proponents seek to make the next wave of enduring process improvements, detailed practices, attuned to the particular conditions of capital facilities projects, are being developed. These detailed mapping practices are a required first step in improving the green delivery processes, facilitating understanding of the processes for improvement.

A conceptual connection between the end user and the environment was drawn in relation to process waste reduction. By identifying and eliminating waste, sustainable outcomes can be enhanced through utilizing delivery processes that are better equipped to maximize value generation by fulfilling the unique needs of green building projects.

The L&G modeling protocol satisfies these needs while serving as a template for L&G researchers to map individual projects and enabling development of a process model to understand green building delivery. Researchers as well as industry can apply the protocol to map and improve their green building delivery processes and to compare their process maps to those developed by L&G for further improvement.

Acknowledgment

This material is based upon work supported by the National Science Foundation under Grant No. 0547324 and by Penn State's Office of Physical Plant which are gratefully acknowledged. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation or Penn State's Office of Physical Plant.

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Lean Construction: Prospects for the German construction industry

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Abstract

There is little, if any, information available about the range and dissemination of lean concepts among construction companies in Germany. Building on the methodologies and conceptual frameworks used in earlier work in the UK (Common *et al.*, 2000) and the Netherlands (Johansen *et al.*, 2002) this study carried out a similar survey among German construction companies to discover the current understanding of lean principles, perceptions of lean and trends in lean development. Qualitative and quantitative analysis of an email questionnaire sent to large German construction companies indicates that there is little awareness of lean in the German construction industry and that hardly any company uses lean concepts on a company wide basis despite evidence that procedures and techniques that are used on German construction sites are generally consistent with lean construction practice. There appears to be cultural resistance to a manufacturing derived, production-system-view of construction.

Keywords: Lean construction in Germany, Lean penetration

Introduction

Lean concepts have been brought to the construction industries of Australia, Brazil, Denmark, Ecuador, Finland, Peru, Singapore, UK, USA and Venezuela (Ballard and Howell, 2003a). However, surveys in the UK (Common *et al.*, 2000) and the Netherlands (Johansen *et al.*, 2002) strongly suggest that the construction industry has generally been slow in taking up lean concepts. A comparison of the surveys also reveals that the two countries differ in their approach to lean construction (Johansen *et al.*, 2002). With regard to the German construction industry, there is little, if any, information available about the range and dissemination of lean concepts among construction companies.

The intention of this study is to conduct a survey among German construction companies to disclose the current understanding of lean principles, perceptions to lean and trends in lean development. In addition, the study is meant to reveal how far current practice and mentality affect the development of a lean culture and to see if the German experience has anything in common with that of the UK and the Netherlands.

The study basically followed Common et al’s (2000) approach adopted during their UK survey. A quantitative technique was employed for collecting the data; followed

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by a qualitative, interpretative analysis. Data were gathered by conducting an e-mail survey with premier construction companies in Germany.

Background

Implementation of Lean Concepts in Construction

Implementing lean concepts means applying tools and techniques throughout the stages of a project. A theoretical foundation is provided through the transformation-flow-value view and further aspects of management theory and complexity theory. It seems, however, that implementing lean concepts requires a fundamental change of traditional structures in terms of both organisation and behaviour. Howell and Ballard (1998) advise us that one has to develop system thinking and to understand the difficulty of change mental models. What is more, one has to accept deep resistance to decentralised decision making. Garnett *et al.* (1998) made the point that what is often overlooked is that any organisational change process is put forward by people. During a collaborative implementation effort by seven Chilean construction companies as discussed by Alarcón and Diethelm (2001), Alarcón *et al.* (2002), and Alarcón and Seguel (2002) insights were provided indicating the need for commitment and ownership at all levels for the success of lean processes. Other studies show similar findings. For example, research on the introduction of Last Planner to a project in the UK raised structural and cultural problems, particularly with sub-contractors (Johansen and Porter, 2003). Considering the implementation of Last Planner from a sociological viewpoint Johansen *et al.* (2004) conclude that cultural barriers are still inherent in the industry. It appears that a substantial change has not taken place yet. Two surveys in the UK (Common, 2000) and in the Netherlands (Johansen *et al.*, 2002) suggested that the construction industry has generally been slow in taking up lean concepts. At the time the surveys were executed, construction companies had adopted lean principles only in a loose manner. Both studies revealed a limited knowledge of lean construction and varying perceptions among construction companies.

To sum up, the majority of the studies on lean implementation underpin the potential for improvement through ‘leaner’ construction. Equally they expose structural and cultural obstacles in encouraging people to adopt lean concepts. Changing traditions and behaviour, however, seems to be a necessary precondition for implementing lean construction.

The German Construction Industry

German construction has seen a declining investment trend over 10 years after the boom in early 1990’s (Federal Office for Building and Regional Planning - Bundesamt für Bauwesen und Raumordnung, 2004). This trend is expected to continue. Information from the Federation of the German Construction Industry (*Hauptverband der Deutschen Bauindustrie*) indicates that the share of actual construction work carried out by the larger companies is declining. Bosch and Philips (2003) point out that the majority of the larger German building firms have developed into general contractors and building service companies. The common procurement method in Germany has changed to general contracting (Hochstadt, 2002). The larger companies take on the position of a project management organisation while the construction work itself is principally sub-contracted to smaller companies.

German industry is highly regulated. Construction work is primarily regulated by the German Building Contract Code (*Vertragsordnung für Bauleistungen, or VOB*). It is common practice in the German construction industry to base awarding procedures and contractual relations on the VOB (Bosch and Philips, 2003). A unique feature of the German construction industry is the monopoly of the master craftsperson, which "ties the management of building firms within the handicraft trades to proof of qualification and thus constitutes an important barrier to an increase in the number of low-qualified self-employed people, existing, for example, in the Untied Kingdom" (Bosch and Philips, 2003). The Handicrafts Code (*Handwerksordnung*) specifies who is allowed to set up such a business. The accelerated structural change in the industry, the poor economic progression and the intensified internationalisation of the market are expected to slow down the innovative capability of the construction industry (Hochstadt, 2002). In order to meet the challenges in the German construction industry, reforms have been implemented concerning primarily the vocational training and the Handicrafts Code (Bosch and Philips, 2003).

Research design & method

The questionnaire adopts a quantitative approach in which data are gathered to measure the extent to which principles, which might be considered "lean", have spread throughout the German construction industry. The objectives were to establish how lean techniques have been disseminated among construction companies, how lean thinking has penetrated the industry, and how lean concepts are being understood. To achieve these, data were collected from large companies which were considered to be more aware of and likely to be influenced by innovation on large projects. The questionnaire was sent out to project managers, managing directors or chief executives from 61 companies taken from *Top100 construction companies in Germany* (2005). A response rate of 28% was achieved.

The questionnaire was formulated in close relation to the UK survey (Common *et al.*, 2000). Their respondents had commented favourably on it, it had been successfully applied in the Netherlands later and thus, could be considered sufficiently tested.

However, the conceptual framework on which the British questionnaire was based in 2000 appeared to be insufficient in view of the progress of development in lean construction. The advancement in the field was taken into account by updating the framework accordingly (see *figure 1* later). Additionally, the formulation of the questions made use of a questionnaire developed for measuring a company's conformance to lean ideals by a team of researchers of the Construction Industry Institute (CII) (Diekmann *et al.*, 2003).

After completing the results they were informed further by discussions with one of the responding companies senior managers and with a member of LCI Germany.

Conceptual Framework

In their work Common et al (2000) identified four areas as being fundamental in developing a lean culture, namely Procurement, Planning, Control and Management. Within each area they recognised a number of techniques that were seen as being instrumental for the realisation of lean construction. The techniques documented included Design & Build, Last Planner, Lookahead Planning, Supply Chain Management and Partnering.

However, this framework was considered to be no longer sufficient due to the progress made since the study was carried out. Among the lean construction community today there seems to be an improved understanding for the complexity of the industry and the mutual dependency of its participants. As a result implementation efforts have become more comprehensive. New insights have been gained into the development and application of techniques as well as into the human aspects of lean construction.

Taking into consideration the developments in lean construction up till now, the conceptual framework can now be viewed as comprising eight areas (*Figure 1*).

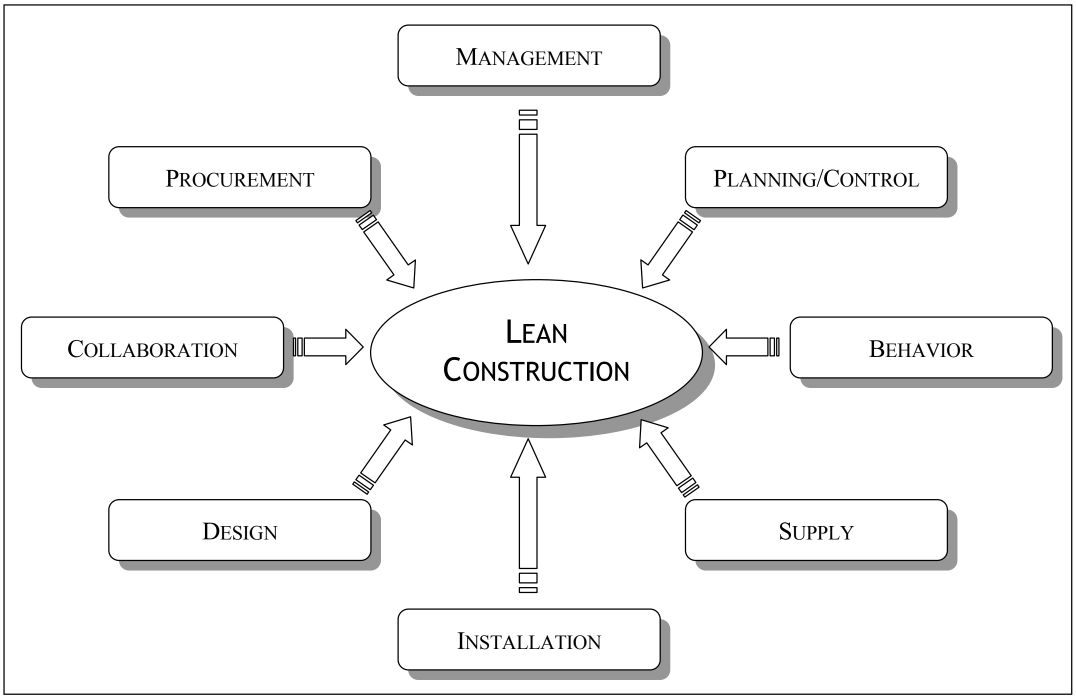

Figure 1: Conceptual Framework

Supporting background to the choice of these areas is given in Appendix A.

Research Results

Dissemination of Lean Concepts in Germany

Procurement

There is a dominance of general contracting although there is evidence that some companies are more involved in what might be considered to be “leaner” forms of procurement. More than three quarters of the responding companies (76%) indicated a share of annual turnover from general contracts above 20%. However, 41% of the responding companies realised up to 20% of their annual turnover through management contracts and/or design & build contracts. The respondents were also asked to indicate the routes adopted for the development of the design. Most frequently respondents delegate design work to external designers which tends to separate the design from the construction process and misses the lean aim of integration.

In general then, the actual state of the German construction industry in terms of facilitating the integration of design and construction by means of contracts and design procedures appears to be at a rather early stage of lean construction development.

Management

A lean approach to construction management had been shown to be essential for adopting a holistic system view to the project as well as to the project's temporary network of service and product providers. In this respect several management tools/concepts have been acknowledged. Within the questionnaire these were listed and the respondents were asked to mark those they are currently involved in.

With 35% TQM seems to be the tool which is most frequently applied within the German construction industry, followed by Benchmarking and Concurrent Engineering. The Last Planner Initiative and Supply Chain Management amount to just 12% each, while Value Streaming has not been indicated at all. The data from the survey also show that 76% of the responding companies are employing either none or just one of the listed lean management concepts. Having identified these as incorporating fundamental lean principles into construction, the current situation in the German construction industry in terms of lean construction management could be considered poor.

The practice of visual management on construction sites, however, appears to be advanced. In the survey the respondents were asked to specify the company's position regarding availability and accuracy of visual information on site. The results illustrated in imply that on most construction sites in Germany information about schedule, quality, safety, productivity and project status are posted and if so, the documents are generally kept up-to-date.

Planning / Control

The underlying principles of planning and control methods in traditional construction and in lean construction could hardly differ more. While the predominant use of the traditional method CPM has been recognised as willingly introducing waste to construction planning, lean tools such as Value Streaming, Last Planner and Lookahead Planning are known to reduce waste and to continuously improve construction activities. Therefore, questions in the survey were directed at planning and control methods as well as improvement measures on site.

The evaluation of the data shows that the customary technique employed within construction planning remains the Critical Path Method. A frequent application of this network planning method was indicated by most of the respondents (62%). In comparison, a frequent application of VS was declared by just 15% of the respondents. Interestingly, about every second respondent, it seems, has never heard of at least one of the "leaner" methods.

The focus of one of the survey questions was on measures taken to systematically quantify unused materials and supplies before disposing, reclaiming or returning them. The aim of another question was to find out whether there are measures in place to assure quality objectives. The evaluation of the responses indicates no more than a modest advance in the verification of unused materials and supplies, the utilisation of quality plans appears to be well developed. Thus, one could claim that, on the majority of construction sites in Germany, certain procedures are maintained which might be considered as conforming to lean.

Collaboration

Throughout the study the high demand for effective communication and collaboration practices in lean construction has been emphasised. A wide range of collaboration technologies has been put forward with reference to lean construction. It is argued that a frequent use of collaboration technology would point towards lean conformance. How frequently German companies are applying collaboration technologies to construction has been established

The results demonstrate that management systems for electronic data are regularly employed by the companies participating in the survey. Project Information Systems are also used within a reasonable level, bearing in mind that a third of the respondents picked “mostly” (25%) or “always” (8%) for this tool. Less popular are text or video conferencing technologies as well as 3D Studios and VR Tools.

Taken as a whole, the situation in the German construction industry in terms of utilising collaboration technology can be seen as progressive. However, the findings from the study give the impression that the focus is on exchanging electronic data rather than applying sophisticated design technologies.

Behaviour

The respondents were asked to specify to what extent employees are sharing their thoughts and if the upper management is generally committed to change. It seems that an open exchange of ideas and views among employees is a common habit in the German construction industry. This can be seen as facilitating the change process during the implementation of lean concepts. Only a minority of the respondents (6%) appear to be convinced that employees do not share their thoughts at all. In terms of willingness to change, the results show the upper management to be generally committed to changes within the company.

With regard to these behavioural aspects it could be hoped that, as far as the attitudes of people involved are concerned, the aim of transforming a traditional construction company in Germany into a lean construction company are not without prospects. However, there are more than just a few other aspects of human behaviour that needed to be looked at before this statement could be generalised.

Design

The respondents were asked if they used “lean” tools such as DSM, 3D Studios or VR in the design process.

Design Structure Matrix is hardly used at all to optimise the order of design tasks. Thirty-one percent of the respondents stated they never used this technique and to 62% of the respondents it was complete unknown. However, 8% of those using DSM were employing it at all times. This might mean that there is a high potential for improving the design process.

Supply

The respondents were asked to indicate their use of SCM, Value Streaming, JIT and Partnering. Partnering seems to be well established within the industry with 47% claiming to be involved in this concept.

The application of JIT as one of the management concepts was document by just 24% of the respondents. Considering that this concept has been known to several industries for decades, this result is disappointing. The concept of SCM is also little used (12%).

Overall the results show that the German construction industry lacks a comprehensive lean approach to supply. Most disturbing of all is the apparent disregard of value aspects. In spite of this, the good level of partnering activities and the existing number of applications of JIT might be considered as indicating a tendency towards lean supply.

Installation

In terms of a lean assembly process on site the importance of reliable and constant flows of work and resources has been stressed. The techniques proposed to achieve this, focus on appropriate site organization, pre-assembly strategies, and synchronization of task and input flows. A selection of such techniques was presented in the questionnaire and the respondents were asked whether they ever applied any of them to the installation process or whether any body else in the company did so.

The coordination of deliveries is common practice in most German construction companies. The employment of the 5S process to the construction site was declared by only 16% of the respondents.

In addition to the list of techniques for improving the assembly process, two sets of opposite statements were given in the questionnaire. One set drew attention to the arrival of materials on site (just-in-time) and the other set was concerned with the handing over of completed work products between crews (flow processing). The respondents were asked to rate their company's attitudes regarding the differing statements.

In most cases materials seem to reach the site shortly before they become installed. Furthermore, completed work packages are made available to the next crew in small batches or at best in a continuous stream. Thus, the synchronisation of task and input flow appears to be well developed.

To sum up, practices on German construction sites give the impression that there is general agreement with lean assembly principles.

Understanding and Depth of Penetration

In order to determine the level of understanding and depth of penetration of lean concepts within the German construction industry the survey questionnaire was also subjected to an interpretative analysis. The questionnaire was structured to facilitate interpretation through cross linking particular issues of lean construction.

Integrating Design and Construction

The results presented in the previous section revealed that the general contract remains the traditional procurement form. A considerable share of the annual turnover made up from design & build was indicated by only two of the responding companies. Thus, the German construction industry seems to be far from an ideal situation of applying lean techniques, as the traditional procurement forms do not facilitate lean approaches to project planning and execution.

With regard to the management of the design process the situation appears just as insufficient as in procurement, as design work is mainly passed on to consultants. Techniques applied in lean construction, however, support concurrent design and planning. This will possibly be impeded when design work is sub-contracted.

Furthermore, the frequent application of the planning technique CPM reflects an inadequate development stage in terms of the understanding of lean principles. Factors that are important for project planning (e.g. transportation, waiting time, rework) are abstracted away when using this method. Techniques that have been recommended for lean planning are rarely used or completely unknown. No more than two companies professed a regular use of some of the lean planning techniques.

The findings point out that a limited understanding of the underlying principles of integrated design, planning and construction exists within the German construction industry. Facilitating procurement forms are rarely used and neither construction design nor planning seems to be completely managed fully in accordance with lean principles.

Holistic Perspective

A second issue that was addressed within the questionnaire was the holistic perspective of lean construction, which has been reflected in the recommendation of comprehensive management concepts. The professed application of these concepts within the individual companies reveals whether construction companies are taking a holistic approach to construction or whether these management concepts are only applied occasionally.

The largest number of respondents indicated the application of either none or just one of the management concepts. An employment of three or more of these was documented by the minority of the companies. From these results it could be argued that a holistic understanding of construction activities might not have been developed yet.

The results also show that little, if any, attention has been paid to value flow, supply chains and lean planning techniques in construction. This remains consistent throughout the survey results. Advancement is only shown on the subject of collaboration and quality aspects of construction.

Customer Value

One section of the survey drew attention to how the respondents believe customer value could best be achieved. The combination of answers revealed the approach the respondents regarded most important to create value for the client.

Interestingly, none of the respondents declared Design, Value Streaming or SCM as important disciplines for providing value for the customer. This is coherent with previous responses, bearing in mind that design and construction are commonly separated and that value generation and flow management concepts tend to be underdeveloped.

A typical set of disciplines selected by the respondents would be Site Production and Quality Assurance in combination with either Planning or Site Management. Both combinations can be perceived as focussing on the production system while emphasising the quality aspect of construction. It could be argued that all of these activities are concentrating on maintaining value and therefore improving the process. However, overlooking that value is created in the design stage and all the way through supply chains probably make an advanced production system inefficient.

It appears that there is no predominant focus on contracts as far as issues of customer value are concerned.

Demand for Change

It has been said that the environment of the construction industry has become increasingly demanding over the last years. The processing of modern-day projects is almost certainly determined by an increasing technological and financial pressure along with a rising interest of the client to be involved in the process. One section in the survey was set out to expose if contractors are aware of these demands and of the need of changing current practices.

An increased demand for lower project costs was identified by all respondents and over 50% recognised growing exigencies concerning faster turnover. In addition, over two thirds of the respondents associated higher demands with technological aspects of construction projects. With regard to client involvement no necessity for change was indicated by the largest number of respondents.

It becomes clear from the responses that the contractors are generally aware of the demands that have been put upon them. Therefore, it could be inferred that they recognise an obvious need for change and may be open minded towards the application of lean concepts in the future.

Perception and Application of Lean Principles

In one question the respondents were asked how they considered the transferability of lean principles to construction. In a further question they had to specify to what extent they thought lean principles were already used within the respective company.

The majority of the respondents expressed scepticism towards the applicability of lean principles by declaring that just a few lean principles could be put into operation within the construction industry. Nevertheless, many of them claimed to consider the future use of lean principles, what may show a growing interest in lean construction.

Only three companies thought that most of the lean principles are applicable to construction. These companies also professed they were using lean concepts as far as contract terms permit. However, the evaluations of the responses that were made throughout the questionnaire exposed that only one of these companies may be considered “lean”.

Discussion

It appears that conversion thinking still governs the German industry and that the integration of lean related project processes has not taken place. This is mainly reflected in conventional procurement methods and the frequent utilisation of planning and control techniques that are responsible for large amounts of waste in construction. The results also give the impression that there is limited understanding of the complexity of the industry network and its potential for improvement. Management concepts that have been proven efficient in the construction industries of other countries are still little used. In particular, the efficiency of mapping techniques and supply chain management has been disregarded.

Looking at German construction sites, it seems, there is general agreement with the lean philosophy. Principles of transparency are implemented and measures are taken to guarantee build-in-quality. Also the production process occurs in a continuous flow while materials are customarily pre-fabricated and delivered at the appropriate time. The responses also indicate a good attitude towards change.

Overall, the results imply good conditions regarding installation, modest conditions in terms of collaboration and behaviour, and inadequate conditions on the subjects of procurement, management, planning/control, design and supply.

Apparently the German construction industry has a lot to catch up on in the way it manages its activities. The greatest deficiency appears to be the narrow perspective contractors might have regarding value generation in general and effective management of the network of service and product providers in particular. However, as far as the implementation of lean construction on the production level is concerned the German construction industry seems to provide a good foundation. Usually the workforces are highly skilled due to the level of education set out by the Handicrafts Code, which facilitates the compilation of multi-skilled work crews. Furthermore, certain lean practices are already in place, so it might be easier to find a way of approaching the lean ideal.

When comparing the findings from the present study with the results of the surveys undertaken in the UK (2000) and in the Netherlands (2002) no significant difference becomes apparent regarding the level and application of lean concepts. In the UK survey Common et al (2000) found that there is "… a distinct lack of understanding and application of the fundamental techniques required for a lean culture to exist." Johansen *et al.* (2002) concluded that, in the Netherlands; "Lean, as a concept appears to be largely unknown although some issues associated with it have some low penetration of the industry. Some companies indicate that a few principles could be applied but there is no indication that they have gone beyond thinking of introducing them." This also describes the situation emerges in the German construction industry.

Supposing that lean construction in the UK and the Netherlands has not been developed much since the surveys were carried out, one could argue that there are certain characteristics existent in all three countries that hinder lean practices to advance. In a telephone conversation between one of the authors and a member of the LCI in Germany, the argument was raised that the level of economical and technological progress of a country influences the development of lean construction (Ott, 2005). Following this it was stressed that some of the countries where lean concepts have successfully been implemented (e.g. Brazil or Chile) are employing more workers and using less technology than, for example, German or UK construction companies do. Thus, it could be argued that lean construction is more effective when implemented in countries which are more people focused than technology focused. However, this argument would need verification since major improvements have been achieved with lean construction in technology driven countries like Australia, Denmark and the USA.

Conclusions and Recommendations

Maylor (2003) suggest that the issue for the modern project manager is the need for a holistic approach to project management. That is, to consider project management to be more than managing the sequence of steps required to complete the project on time and on budget. With lean construction such a holistic approach has been introduced to construction which goes far beyond traditional project management by facilitating a new understanding of construction activities and the industry itself. In recent times, the construction industries of several countries around the world have taken on a lean approach to construction.

The intention of the research at hand was to investigate lean construction in the context of the German construction industry. There was little data available about the development of lean construction in this country. An investigation of the application and understanding of lean concepts and techniques among German construction companies was undertaken to fill the gap in the existing body of knowledge.

In an initial step a thorough analysis of the literature on lean construction relevant to the study provided useful insight into the origin of the lean philosophy as well as the emergence and the consolidation of lean construction. Based on the findings from the literature review a conceptual framework has been developed, which formed the basis for two questionnaire surveys. The received questionnaires were then subject to a qualitative and an interpretative analysis in pursuit of the objectives of the study.

The research suggests that there is little awareness of lean in the German construction industry. No more than a few lean concepts are occasionally applied within the industry. Therefore, the level of how lean concepts penetrate the construction industry is rather low.

An overall evaluation of the questionnaires shows that hardly any company uses lean concepts on a company wide basis. Profound deficiencies were revealed relating to procurement methods and the management of construction projects. Owing to traditional contracting and certain planning methods large amounts of waste are still inherent in the German construction industry. Moreover, the potential for improving the company's performance through employing advanced management concepts such as supply chain management or concurrent engineering, it seems, has not been realised.

On the other hand, the research implies that procedures and techniques that are used on German construction sites are generally consistent with lean construction practice. In particular, aspects regarding build-in-quality and the flow of materials and work crews that are relevant during the assembly process seem to be considered.

However, the majority of the respondents took a critical stand towards the applicability and transferability of lean principles to the construction industry. This might indicate a persistent view of construction as an industry, which can make very little use (if any) of principles that have been developed in the manufacturing industry. Thus, the most difficult barrier to overcome appears to be the mental change process towards a production-system-view of construction.

Recommendations

The present study identifies that the level of development and application of lean construction in the German construction industry has been very low. The UK survey and the Netherlands survey indicated similar findings. In the discussion of the results the argument was put forward whether the development of a lean culture is easier said than done in countries where construction activities are mainly technology focused compared to those where the construction process is people focused. Here further research is recommended. A possible starting point could be Hofstede's four dimensions of national culture – Power Distance, Uncertainty Avoidance, Individualism and Masculinity and Femininity (Hofstede, 1984).

In order to facilitate the development of lean construction in Germany research is considered fundamental that focus on the implementation of individual lean concepts in the context of the construction industry. While doing so, the consideration of the prevailing conditions (i.e. supplier-contractor and client-contractor relationships, the regulatory framework, etc.) are regarded as important.

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APPENDIX A

Background to Figure 1

Having acknowledged the focus on flow processing as being essential for lean construction, the **procurement method** adopted should smooth the progress of design and construction in such a way that they can take place concurrently. Moreover, the procurement method should enable early involvement of downstream players in the upstream process. In this respect integrated procurement strategies such as Design & Build, Management Contracting, Private Finance Initiatives and Partnering have been identified as most effective. In contrast, traditional contracts (e.g. general contracts or sub-contracts) tend to separate the design from the installation process and also the participants within.

In terms of the development of **management concepts** in lean construction much emphasis was given to improving information transparency, managing key service provider, and initiating improvement strategies. Here the principles of Supply Chain Management, Concurrent Engineering and Total Quality Management – previously used solely in the production industry – have been recognised as successfully applicable to the construction industry. Benchmarking could be added as a management concept relevant to lean construction, since it helps to improve performance and competitiveness. The importance of the visualisation of processes and practices as well as the positive consequences of a simplification of procedures has been acknowledged by introducing principles such as Visual Management and Standardisation to the management of construction.

Further techniques that are significant for lean construction have been established in project **planning and control**. These techniques aim at the reduction of variability and uncertainty inherent in construction. Planning and control have been combined, because control in lean construction is primarily achieved by accurate planning near to the execution of the task. The Last Planner System of production control has been identified as the leading concept. Among others the system unifies techniques such as Work Structuring, Pull Scheduling, Lookahead Planning and Weekly Work Planning. Although it may be possible to employ some of these techniques separately, it has been recognised that they are most effective when applied together. This includes the techniques of Constraints Analysis and the Activity Definition Model, which usually come into play during the preparation of look-ahead schedules. With regard to the planning of site activities Continuous Flow Processing has proven very beneficial.

Another fundamental feature of lean construction is **collaboration**. This term covers many aspects from long-term contractual agreements with sub-contractors, suppliers, consultants and clients, via the formation of multi-disciplined teams for a project, to the joint use of information technology for several deliveries or document exchanges. Techniques and tools found to facilitate the collaboration aspect of lean construction include Partnering, Cross-functional Teams and the employment of Document Management Systems or Project Information Systems.

While considering **behavioural aspects** of lean construction it emerged that a successful transformation from conventional practice to lean construction requires participation and dedication from all hierarchical levels, as well as the ability to critically analyse the structure and culture of one's own organisation. These requirements can be generalised as 'commitment to change' and the 'ability to self-criticism'. It has further been acknowledged that certain lean planning techniques demand a 'long-term vision'; others require the 'sharing of incomplete information'. Both aspects were accredited as crucial for the process, but difficult to achieve.

The lean approach to **construction design** was found to employ techniques that help to prevent value loss by diminishing inconsistent decision-making and to stimulate flow by enhancing coordination and information procedures. Techniques that focus on improving decision-making have been identified as Concurrent Design (of the product and the process) and a
Set-based Design strategy. The implementation of Design Structure Matrix, Virtual Design Studios and Virtual Reality Tools were made out as supporting co-ordination and information procedures in lean design.

With regard to the provision of materials to the construction site, **supply principles** have been outlined that facilitate the delivery of materials at the appropriate time, of the desired quality and to the right amount. Apart from advanced information technology typical techniques of lean supply have been acknowledged as Just-In-Time and Kanban. In addition it has been noted that the depiction and evaluation of the entire value stream of supply chains (Value Stream Analysis) improve the delivery process and the product itself.

The organisation and execution of the **installation process** in lean construction has been recognised as primarily following flow principles. This applies to the movement of work crews and materials as well as to the production processes themselves. CFP and the LP have been identified as techniques for planning and organising site tasks and crew movements. First Run Studies and Pre-Fabrication Strategies have been considered as minimising uncertainty in production processes. Regarding the effective administration of the necessary materials on site, the utilisation of a site logistic tool such as the 5S-Method has been proofed helpful.

Lean Construction – 2000 to 2006

Thais da C.L. Alves[1] and Cynthia C.Y. Tsao[2]

Abstract

Construction management research in the early 1990s called for Architecture-Engineering-Construction (AEC) researchers and practitioners to investigate how the theory, principles, and techniques associated with the Toyota Production System (TPS) can be abstracted and applied to the planning and management of AEC projects. Since then, the International Group for Lean Construction (IGLC) has become a focal point for showcasing research efforts in this regard. Contributors to IGLC proceedings include academics, practitioners, and consultants covering a range of project types, project phases, and countries. By analyzing the keywords listed by IGLC papers from 2000 to 2006, we hope to identify major research areas to provide a perspective as to what Lean Construction means in 2006. We will also make recommendations for future research and identify strategies for streamlining the IGLC community's efforts in categorizing papers for fellow researchers.

Keywords: Lean Construction, Lean Construction research, Lean Construction implementation, IGLC, IGLC conferences, content analysis, keywords analysis, research trends

Introduction

Koskela (1992) served as a catalyst for research in Lean Construction. Since then, researchers working closely with practitioners have been investigating the theory, principles, and techniques of lean project delivery. These efforts cover a range of project types (e.g., housing, commercial, and industrial projects) and project areas (e.g., project definition, design, supply, assembly, and use). By understanding the extent of Lean Construction knowledge, researchers can better structure their efforts so that they build upon existing knowledge and generate new insight into less-investigated areas. This paper reviews the conference proceedings for the International Group for Lean Construction (IGLC) from 2000 to 2006. Adapting from the content analysis method, we begin developing an analysis of IGLC keywords to understand recent trends in research and practice. Our goal is to report on what we observed in IGLC papers, not to interpret the degree of "lean-ness" or to define "lean" categories or clusters.

This paper will begin with an explanation of the content analysis approach and how we adapted it for our work. Then, we will outline our data analysis results and identify the emerging clusters of Lean Construction research. From our analysis, we will highlight

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recent advances made by IGLC researchers and practitioners and make recommendations for areas that would benefit from additional research. Finally, we will revisit our research hypothesis and questions to determine the insight provided by our research effort.

Research Method

This paper adapts the content analysis method for data collection and data analysis to an analysis of IGLC keywords. "Content analysis came to prominence in the social sciences at the start of the twentieth century, in a series of quantitative analyses of newspapers, primarily in the United States" (Robson 2002, p.351). This method of analysis looks for trends in the contents of documents (e.g., letters, television programs, notices, films, and textbooks).

According to Robson (2002, p.352-357), a content analysis can be developed through the following steps:

- Start with a research question
- Decide on a sampling strategy
- Define the recording unit
- Construct categories for analysis
- Test the code on samples of text and assess reliability
- Carry out the analysis

We next describe how each of these steps contributed to our keywords analysis.

Start with a research question

We identified two research questions to guide our work: "What does Lean Construction mean in 2006?" and "What are the major research topics that interest the Lean Construction community?" We anticipated that Lean Construction research relied heavily on a few topics (e.g., Last Planner) and that these topics provided the foundation for Lean Construction as a new philosophy of management as suggested by Koskela (1992). Thus, these questions served as a starting point for the research presented in this paper.

Decide on a sampling strategy

We decided to collect data from papers published in the conference proceedings of the International Group for Lean Construction (IGLC) because this conference strives to represent the state of the art of Lean Construction research and implementation. IGLC conferences are often the venue of choice for Lean Construction researchers and practitioners to first display their work and discuss different facets of Lean Construction research and implementation (e.g., methods and tools, work structuring, supply chain management, human aspects of implementation, change management, etc).

The vision of the IGLC as stated on their website (http://www.iglc.net/) is called Lean Construction and their goal is "*to better meet customer demands and dramatically improve the AEC process as well as product. To achieve this, [they] are developing new principles* *and methods for product development and production management specifically tailored to the AEC industry, but akin to those defining lean production that proved to be so successful in manufacturing*” (IGLC Portal 2006).

For our analysis, we decided to sample all conference papers published from 2000 to 2006 since they represent Lean Construction research in the 21st century, and other papers have analyzed the question “What is Lean Construction?” on multiple occasions outside of this sample (e.g., Koskela 1993, Melles 1994, Howell and Ballard 1998, and Howell 1999).

Define the recording unit (Abstracting from content analysis)

We recognize the value of the content analysis approach and the tools available (e.g., search engines) for carrying out such an analysis. However, since IGLC allowed authors to define keywords on their own, we decided to abstract from the content analysis methodology and apply it to the study of keywords instead. In doing so, we are hypothesizing that the study of keywords will provide a sufficient perspective into the most popular research areas and reveal areas which may warrant more attention by practitioners and researchers.

Accordingly, we selected the keywords indicated by the authors of IGLC conference papers as the recording unit for the keywords analysis. We acknowledge the bias introduced by IGLC authors when they choose keywords to represent their work since there are no rules or set of catalogued keywords for describing IGLC conference papers. We also recognize that IGLC authors may indicate as few or as many keywords as they please and this impacts the final results of our keywords analysis.

Construct categories for analysis

Robson (2002, p.355) notes that different categories of analysis can be used in content analysis (e.g., subject matter, direction, values, goals, methods, actors, location, etc.). For this paper, we decided to analyze the category of subject matter. Our research objective is to analyze the keywords indicated on IGLC conference papers from 2000 to 2006 to develop insight as to what Lean Construction has meant for the IGLC community. Initially, we looked to the theme areas of IGLC conferences to shape our categorization. However, as these theme areas changed from one conference to the next, we decided to first survey the frequency of all keywords and then formulate categories based on clusters of words that stood out. The following list describes how keyword clusters emerged:

- <u>Common root words</u>: These words showed up frequently combined with other words to form a variety of keywords (e.g., cost, design, supply chain, and value). After gathering all keywords associated with a common root word, we either selected the common root word or the most popular keyword as the cluster name.
- <u>Related words</u>: We grouped these words based on their connection to a common interest area. For example, the keywords CPM and line of balance are scheduling techniques, so we grouped them under the scheduling cluster. Likewise, the keywords 3D / 4D CAD, simulation modeling, and virtual reality are all information technology tools, so we gathered them within the information technology cluster.

- Words with an embedded meaning: A few keywords have a special meaning within the IGLC community. For example, the keywords percent plan complete, phase planning, and weekly work plan are all elements of the Last Planner System (Ballard 2000a). As a result, they were grouped under the Last Planner cluster.

Keyword clusters with 10 or more paper appearances are listed in Table 1, and the related keywords are listed under each keyword cluster within the Appendix section.

Test the code on samples of text and assess reliability

Since the codes used are keywords selected by IGLC authors, we did not test their suitability in describing IGLC papers. We assumed the indicated keywords were sufficient in representing their papers, and we acknowledge this limitation of our keywords analysis.

Carry out the analysis

For our analysis, we sorted the keywords in a Microsoft Excel® spreadsheet and analyzed keyword frequency using the PivotTable function. According to Robson (2002, p. 399), "exploratory analysis explores the data, trying to find out what they tell you" and "(c)onfirmatory analysis seeks to establish whether you have actually got what you expected to find." Thus, our data analysis was both exploratory and confirmatory.

In the exploratory stage of this research, we calculated the frequency of certain keywords and looked for patterns in the data. Then, we tried to group words that had similar meanings. For instance, we initially anticipated that the Last Planner System (LPS) (Ballard 2000a) was often viewed as an embodiment of Lean Construction, so the LPS and its components (i.e., Percent Plan Complete, PPC, lookahead planning, and phase scheduling) would frequently show up as keywords. In other situations, some strings of words referred to broader meanings (i.e., categories), so we grouped them as major categories in the keywords analysis. For example, we categorized keywords 'complexity', 'complex projects', and 'complex systems' as 'complexity' and keywords 'value', 'value stream', and 'value generation' as 'value'.

In the confirmatory stage of our research, we noted more popular areas of Lean Construction research and implementation as indicated by the keywords analyzed. Furthermore, by grouping select keywords into broader categories, we developed a better understanding about what IGLC researchers and practitioners have been doing recently in terms of both research and implementation.

After we analyzed the data and determined the frequency of keywords for different categories, we occasionally used the abstracts of these papers to confirm whether our categorizations of certain keywords were appropriate. This task:

- provided examples that reinforce our comments on IGLC research
- increased the robustness of our analysis by identifying source papers as references.

Lean Construction – 2000 to 2006

We analyzed the abstracts and keywords for all 357 papers from the 7 IGLC conferences from 2000 to 2006. We collected a total of 1,710 keywords from 329 papers (i.e., 92.2% of all IGLC papers from 2000 to 2006). As mentioned earlier in the 'Construct categories for analysis' section, we grouped major keywords with their related terms into keyword clusters (see Appendix). Then, we gathered clusters with 10 or more keyword appearances in Table 1. We accounted for a total of 810 keywords, averaging about 2.45 keywords per paper. Thus, our analysis covers 47.4% of all IGLC keywords from 2000 to 2006.

Research hypothesis

An initial survey of keywords indicates that Lean Construction research and implementation covers a broad range of topics. As a result, we hypothesize that the study of keywords of IGLC conference papers is sufficient to provide an overview of what has been investigated by practitioners and researchers in the Lean Construction community.

Keywords analysis

As one would expect for IGLC papers, the term 'Lean Construction' tops the list presented in Table 1. This term is frequently selected as a keyword because it signifies that the paper refers to research or implementation of Lean Construction theory, principles, and techniques. The same observation can be made for the keywords 'construction' and 'lean production' as the papers presented at IGLC conferences often:

- investigate project-based production systems within the AEC industry
- attempt to abstract theory, principles, and techniques from Lean Production for application within the AEC industry.

Table 1: Frequency of Keywords and Related Keywords in 2000-2006 IGLC Papers

Keyword Cluster	Keyword Instances	Related Keywords	Total Keywords	Percent
lean construction	94	0	94	5.5%
design management	10	61	71	4.2%
culture and human aspects	5	55	60	3.5%
production management	11	49	60	3.5%
value	13	39	52	3.0%
scheduling	12	36	48	2.8%
supply chain management	20	24	44	2.6%
process	5	33	38	2.2%
last planner	14	23	37	2.2%
cost	2	33	35	2.0%
preassembly / prefabrication	14	18	32	1.9%
information technology	5	26	31	1.8%
safety	7	19	26	1.5%
project management	18	6	24	1.4%
performance measurement	11	11	22	1.3%
construction	17	4	21	1.2%
waste	10	8	18	1.1%
complexity	11	6	17	1.0%
implementation	13	3	16	0.9%
theory	6	9	15	0.9%
lean production	14	0	14	0.8%
client / customer	3	10	13	0.8%
quality	3	9	12	0.7%
work structuring	10	0	10	0.6%
Subtotal	**328**	**482**	**810**	**47.4%**
Total Keywords 2000-2006			1710	

12.1% - Project Management

This larger cluster contains the smaller clusters Production Management (3.5%), Scheduling (2.8%), Process (2.2%), Last Planner (2.2%), and Project Management (1.4%).

The keyword Last Planner (Ballard 2000a) is a term unique to the IGLC community. The high frequency of Last Planner System (LPS) and its related keywords (e.g., weekly work plan, lookahead planning, and commitment planning) indicates the importance of this technique to Lean Construction implementation in different contexts. Papers by Glenn Ballard and Greg Howell in IGLC conferences in the 1990s stress the importance of first stabilizing work flow on AEC projects by shielding production against uncertainty before other improvements could be made (Ballard and Howell 1994a, 1994b; Howell and Ballard 1994). These papers originally presented at the 2nd IGLC Conference in Santiago, Chile, planted a seed in the IGLC community by highlighting the need for managing production on AEC projects beyond productivity control. These papers also reinforced Laufer and Tucker's (1987) recommendation for the need to acknowledge uncertainty in construction and properly take it into account in the planning process.

Many researchers and practitioners from different parts of the globe first develop experience in Lean Construction by implementing the Last Planner System (LPS) on AEC projects (e.g., Thomassen et al. 2003)[3]. However, recent case studies have started to reveal that Lean Construction implementation can occur without the explicit use of the LPS (Matthews and Howell 2005).

4.2% - Cost, Performance Measurement, and Implementation

This larger cluster contains the smaller clusters Cost (2.0%), Performance Measurement (1.3%), and Implementation (0.9%).

Cost and performance measurement provide important indicators that help practitioners recognize and appreciate the impact of implementing lean on AEC projects. Implementation allows AEC practitioners to test out principles and techniques identified by researchers to confirm or refute their theoretical understanding of lean project delivery. In particular, IGLC papers have investigated the use of activity-based costing (Kim and Ballard 2001), performance measurement (Lantelme and Formoso 2000), target costing (Ballard and Reiser 2004, Granja et al. 2005), and benchmarking (Alarcón et al. 2001, Thomassen et al. 2003) to assist lean implementation on AEC projects. Furthermore, shifting project resources upfront to improve project planning may dramatically increase the benefits from investing in lean (e.g., Tsao et al. 2000, Tsao et al. 2001). To promote broader adoption of lean by the AEC industry, we recommend that future research should investigate how to measure the benefits of implementing lean earlier in project delivery.

4.2% - Design Management

Although design management precedes job-site management in lean project delivery, Lean Construction implementation often begins with management of job-site work instead of design management. This happens because the LPS is effective in managing the transformation of tangible input resources into outputs of installed work at the job-site. In contrast, design typically involves the transformation of intangible resources into outputs of design data, so constraints become harder to identify and manage (Tzortzopoulos et al. 2001). Thus, while many projects have implemented lean in job-site management, fewer projects have attempted lean implementation during design. As a consequence, it is uncommon for design researchers to access and aggregate results from multiple projects as

[3] We hope practitioners and researchers recognize that use of the LPS is not synonymous to Lean Construction implementation. Rather, it is typically the first step of many in the lean journey on AEC projects.

is sometimes the case with research in job-site management (e.g., Bortolazza and Formoso 2006). Instead, IGLC papers in design typically use case studies to explore the effectiveness of different principles and techniques in supporting lean implementation during design development.

For example, IGLC papers have investigated the suitability of techniques such as dependency structure matrices (Hammond et al. 2000), the LPS (Tzortzopoulos et al. 2001), and building information modelling (BIM) (e.g., Sriprasert and Dawood 2002, Khanzode et al. 2005) for use in lean design management. IGLC papers have also investigated various principles that can be used to help guide product design development. For example, Gil et al. (2000) emphasized the value of involving specialty contractors in product design development while Lee et al. (2003) demonstrated how reliability and stability buffering can help reduce the impact of iterative cycles on the later stages of an AEC project.

3.8% - Value and Client/Customer

This larger cluster contains the smaller clusters Value (3.0%) and Client/Customer (0.8%).

Since value is defined by the client/customer, value research is naturally linked with client/customer research. IGLC papers have investigated how an AEC project generates value for the client/customer (Miron and Formoso 2003, Whelton and Ballard 2003, Barshani et al. 2004). In particular, Ballard et al. (2001) outlined an ends-means hierarchy which describes in detail how project-based producers maximize value on AEC projects. In addition, IGLC researchers have borrowed value stream mapping from the Lean Production toolkit to isolate value-adding work on AEC projects (e.g., Freire and Alarcón 2000, Arbulu and Tommelein 2002, Bulhões et al. 2005).

3.5% - Culture and Human Aspects

It is often said that Lean Construction researchers have neglected culture and human aspects on AEC projects (Macomber 2006). Surprisingly, our analysis revealed that the category 'culture and human aspects' is among the top 10 categories listed in Table 1. It is worth noting that the word 'human' is often used to designate keywords in this category as well as in the 'safety' category. Research in culture and human aspects has involved efforts to develop competencies necessary for Lean Construction implementation (Hirota and Formoso 2001; Pavez and Alarcón 2006) and investigations in project culture (Thomas et al. 2002, Zuo and Zillante 2005). Criticisms about Lean Construction and its impact on human resource management were also present in the sample of papers analyzed (e.g., Green 2000).

2.6% - Supply Chain Management

In the group of papers analyzed, the papers on Supply Chain Management are in most cases theoretical or descriptions of how companies work within their supply chains. The papers have dealt with theoretical models (e.g., Childerhouse et al. 2000; Alves and Tommelein 2006) and analysis (e.g., London and Kenley 2000; Vrijhoef et al. 2001) aiming at explaining how construction supply chains work, their peculiarities, and what should be done to effectively implement supply chain management in construction.

There are also papers that describe how specific supply chains work (e.g., Akel et al. 2001; Elfving et al. 2002; Azambuja and Formoso 2003; Fontanini and Picchi 2004). In these cases, researchers describe how actors in a specific supply chain interact, how the supply chain operates and what its main problems are, opportunities for improvement, and good practices that can be replicated to other supply chains in construction.

However, papers on cases about the implementation of supply chain management concepts across 4 or more companies are lacking in IGLC proceedings. This may be due to the difficulty researchers and practitioners have in carrying out changes along multiple tiers of a supply chain. Also, the construction industry may be learning slowly about the need to manage not only their companies, but their supply chains as well. So, in spite of the high frequency of Supply Chain Management keywords in the papers analyzed, the IGLC community has a long way to go to effectively implement Supply Chain Management in construction.

1.9% - Preassembly/Prefabrication

In the IGLC conferences analyzed, preassembly and prefabrication papers are grouped in a single section which also involves papers on open building. Prefabrication has been seen as an essential step towards industrializing construction (Koskela 1992). However, poor planning and haphazard development of prefabrication initiatives, amongst other factors, may have led the industry to downplay the potential benefits achieved with preassembly and prefabrication (Gibb 1999). Recently, efforts have been made to improve the assessment of prefabrication vs. traditional construction (e.g., IMMPREST discussed by Pasquire et al. 2005) as this seems to be a major factor to convince clients about the benefits provided by prefabrication and preassembly to construction projects. Researchers have also investigated ways to implement lean concepts to prefabricate construction components (Ballard et al. 2002) and to analyze the benefits achieved through off-site fabrication. Tommelein (2006), for instance, used discrete-event simulation to run experiments to illustrate the results achieved through prefabrication of standard spools for a major project.

1.8% - Information Technology

Researchers have used information technology (IT) to advance in different areas in the IGLC community. IT is understood here not only as the development of tools to support Lean Construction implementation but also the use of programming languages and software packages to support design, planning, procurement, and other disciplines in construction. IT has been used to help in the implementation of Lean Construction in planning and control (e.g., Choo and Tommelein 2000; Alarcón and Calderon 2003) but also in design (e.g., Kagioglou et al. 2003, Pasquire et al. 2005), knowledge discovery and management (Soibelman and Kim 2000) and production system design (e.g. Alves et al. 2006) to name a few. Nevertheless, one should not forget about the need to solve underlying problems found in the construction, risking automating inefficient processes or collecting meaningless data. "*We cannot achieve breakthroughs in performance by cutting fat or automating existing processes. Rather we must challenge old assumptions and shed the old rules that made the business underperform in the first place*" (Hammer 1990, p.108).

1.5% - Safety

IGLC papers have investigated managing safety through production planning and control (Saurin et al. 2002, 2006), developing new approaches to construction safety (Howell et al. 2002, Abdelhamid et al. 2003, and Mitropoulos et al. 2003), using performance measures to improve safety on AEC projects (Marosszeky et al. 2004), and forecasting risk levels for workers as a function of time (Sacks et al. 2005). We suggest that future safety research should seek to demonstrate the correlation between reliable execution of work and improvements in safety performance to help demonstrate the value of lean project delivery to owners.

1.1% - Waste

Banishing waste is one of the goals of Lean Construction (Koskela 1992). In IGLC papers, the keyword waste has been used to designate research on measuring waste rates, identifying its causes and proposing recommendations for its elimination. Identifying and quantifying waste should not be a goal by itself. The literature suggests that a proactive analysis of projects should aim at banishing waste before it materializes, through better design, planning, control, procurement and coordination among the construction supply chain actors (Formoso et al. 2002). Furthermore, waste reduction should not be limited to the upper levels of a supply chain. For example, if a third-tier supplier held considerable inventory to help a second-tier supplier operate just-in-time, the owner will still inadvertently need to pay for the inventory holding costs incurred by the third-tier supplier. Rather, lean project delivery must strive to minimize work-in-progress by achieving continuous workflow from raw materials to installed work (Womack and Jones 1996). Examples of research to banish waste from construction include Polat and Ballard’s (2004) work, which have identified waste sources in the Turkish construction industry and proposed recommendations for their elimination. Also, Tsao and Tommelein (2001) have identified initiatives by a light-fixture manufacturer to streamline its own flow of work and that of its clients.

1.0% - Complexity

The study of construction projects and supply chains as complex systems has gained momentum in recent years. Complex systems are systems whose component parts are highly integrated, and changes in any component may trigger system-wide impacts (Calvano and John 2004). Central to this concept is the idea that the interaction between all parts of a system will result in outcomes that differ from the sum of the outcomes of each individual part. The keywords related to complexity have been used to describe and analyze construction as a complex system in multiple theoretical papers, many of them written by Danish researcher Sven Bertelsen (e.g., Bertelsen 2003). Researchers have also investigated how complex projects can benefit from the use of Lean concepts (Al-Sudairi et al. 2000) and how projects can have their production systems effectively designed as a means of improving their performance vis-à-vis the level of complexity inherent to them (Schramm et al. 2006).

0.9% - Theory

IGLC conferences have always addressed theory either explicitly as a section or embedded in papers that contribute to theory generation through practice (e.g., Howell and Ballard 1998, Khanzode et al. 2005, Luo et al. 2005). Currently, IGLC conferences designate theory as a major theme area for research. Papers in this section usually attempt to broaden the understanding of construction characteristics (e.g., Bertelsen 2003), the theory of production (e.g., Ballard et al. 2001), adaptation of theories to construction management (e.g., Macomber and Howell 2003), and the study of complexity issues in construction (Al-Sudairi et al. 2000).

0.7% - Quality

Quality can be thought of as an outcome of work developed under lean concepts as well as the basis for the development of sound work packages that will help production meet its goals. Recently, papers on quality have been grouped thematically with papers on the environment and safety in IGLC conferences. Papers on quality have investigated quality assurance (Saha and Hardie 2005) and quality tools (Marosszeky et al. 2002). Others have discussed quality and its application in the design process (Emmitt 2003), in the definition of buffers (Lee et al. 2003), and in production control (Marosszeky et al. 2002).

0.6% - Work Structuring

Earlier work structuring-specific research described how AEC practitioners manage (or fail to manage) the balance of supply chain-, product-, process-, and operations designs to generate value for different stakeholders (Tsao et al. 2000, Tsao and Tommelein 2001, and Milberg and Tommelein 2003). Later case studies examined how better work structuring can yield improvements in overall project cost and schedule (Al-Sudairi 2004, Schramm et al. 2004, and Alarcón et al. 2004). However, practitioners within these case studies usually do not manage their work explicitly as a work structuring process. Rather, IGLC researchers interpret their work theoretically as work structuring practice. Thus, future IGLC papers should examine how to help AEC practitioners engage in work structuring explicitly and promote global optimization through the use of techniques such as relational contracting.

Under-Represented Topics – Suggestions for Future Work

Based on the keywords analysis presented in this paper, some topics appear to be under-represented in IGLC conference papers when compared to those topping the list in Table 1. This may indicate that researchers and practitioners alike have not given enough attention to certain areas despite their potential contribution towards achieving IGLC goals. However, this interpretation of under-represented topics is based on the research areas noticed and identified by the Authors and do not represent an all-inclusive list. Rather, we provide the following discussion as a starting point for identifying areas that warrant further study and anticipate other researchers will identify more areas after reviewing our research results. For each under-represented topic, we will discuss its potential role in advancing Lean Construction research and practice.

- Strategy – The keyword strategy appeared in four occasions in the following terms: corporate strategy, competitive strategy, delayed differentiation strategy and postponement strategy. This indicates a lack of papers that describe cases in which Lean Construction implementation has actually been linked to business strategy. Besides, questions such as "Does lean construction improve construction companies' competitiveness and market share?" (Barros Neto 2002) should be investigated to evaluate to which extent Lean Construction actually contributes to helping firms make money and deliver what the market wants.
- Return on Investment – Papers on cost management can be found in the sample analyzed, however, only one paper mentions as a keyword the term "return on investment". This may be a prolific topic to be researched as it would provide the IGLC community an idea of the costs and benefits related to Lean Construction adoption and convince owners to ask for lean project delivery.
- Linguistic Action, Language/Action Perspective – The papers related to Linguistic Action and Language/Action Perspective (e.g., Vrijhoef et al. 2001; Macomber and Howell 2003; Azambuja et al. 2006) analyzed how people exchange information, make requests and offers, and determine their level of commitment to the promises they make on AEC projects. Specifically, researchers have investigated how practitioners manage the network of commitments, so additional research would thus deepen our understanding of how to improve reliability on AEC projects.
- Sustainable Construction and Green Building – Sustainability issues have become increasingly important in construction projects due to owner awareness about energy efficiency, life-cycle costs and social responsibility. However, in IGLC conferences this topic has not been very popular among researchers and practitioners - only four papers from the sample investigated have dealt with this topic. The keywords green building (one instance), sustainable construction (one instance), sustainability (two instances), and sustainable development (one instance) appeared for a total of five times. The papers have discussed how Lean Construction can incorporate environmentally-friendly concepts to bring savings to the owner throughout a project's life cycle without compromising production goals (e.g., Degani and Cardodo 2002; Luo et al. 2005). We believe sustainability issues should receive more attention from the IGLC community because of its growing importance and potential benefits to the AEC industry and society as a whole.
- Contracts – The Lean Construction Institute has been advocating relational contracting as a means to improve assignment and management of work on AEC projects. The Lean Construction Journal recently devoted an entire issue to relational contracting (LCJ 2005) which highlighted advances in practice achieved by companies such as Sutter Health of California (Lichtig 2005) and Integrated Project Delivery of Florida (Matthews and Howell 2005). However, with a few exceptions (e.g., Toolanen et al. 2005, Toolanen and Olofsson 2006), the IGLC community has been slow to respond to the challenge of studying relational contracting. We speculate that this may be due to the fact that IGLC researchers have stronger relationships with designers, contractors, and fabricators than the owners who decide on the types of contracts to use on AEC projects. Despite this limitation, we suggest that researchers strive to understand how to implement relational

contracting, measure its outcomes, and explain project results to help provide guidance to owners that are interested in working towards lean project delivery.

Conclusions

The research questions, "What does Lean Construction mean in 2006?" and "What are the major research topics that interest the Lean Construction community?" were used as a starting point for the research presented in this paper. Throughout the paper, we identified major topics of interest to the IGLC community, and their subsets. From our analysis, we identified the following clusters which contain keywords that appeared 10 or more times in IGLC conference papers from 2000 to 2006:

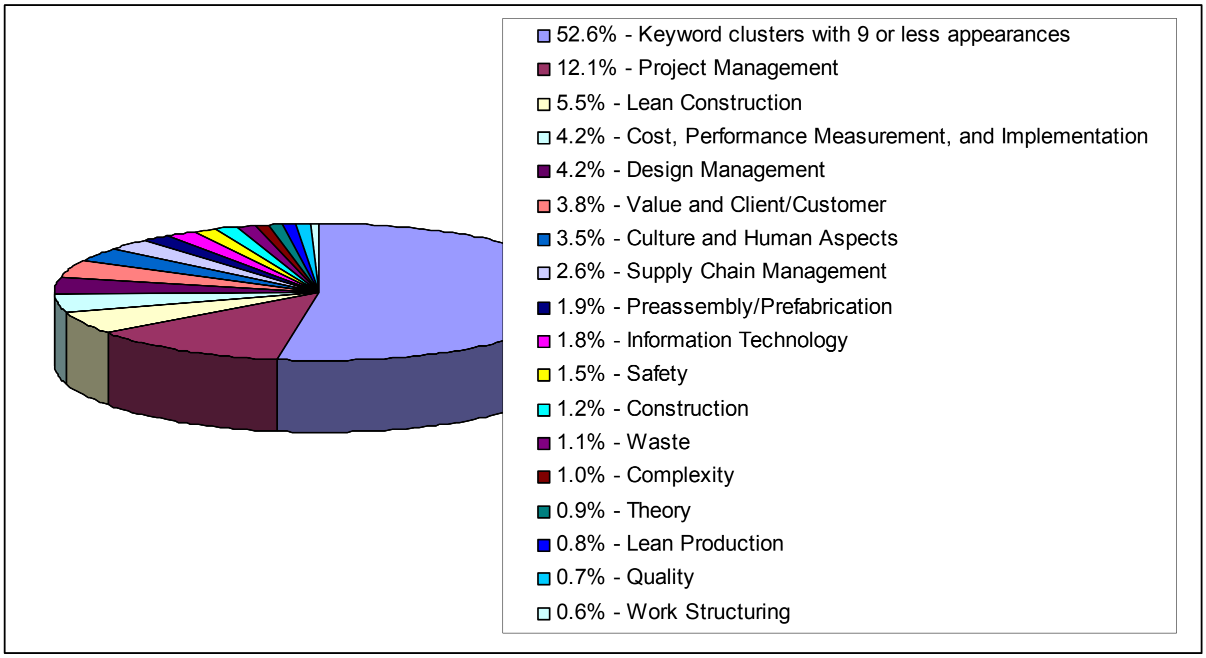

Figure 1: Keyword Clusters and their % Contribution to all IGLC Keywords, 2000-2006

In our discussion of each keyword cluster, we identified relevant papers by researchers and practitioners to substantiate our discussion and address our research questions. Thus, we believe that the keyword clusters identified in this paper and listed in Figure 1 represent the major research topics of interest to the Lean Construction community from 2000 to 2006, and we believe this provides insight as to what Lean Construction means in 2006.

Therefore, in considering our research hypothesis, we conclude that a keyword analysis combined with a review of IGLC papers is sufficient in revealing the primary research areas in the IGLC community from 2000 to 2006.

However, we believe the definition of keywords in an IGLC paper should be done more carefully as they should represent the main topics discussed in the paper. In our research, we found a myriad of terms that define similar meanings. On the one hand, it is beneficial to have the freedom to name whatever keywords best describe your work; on the other hand, too much freedom leads authors to exercise too much creativity in coining old terms with new ones. The excess of keywords and meanings may hamper the definition of a common language to describe what Lean Construction means. As a result, AEC practitioners will be quick to dismiss Lean Construction as "just-in-time" if the IGLC community lacks a common message about the breadth and depth of Lean Construction.

Numerous keywords may also hinder the dissemination of Lean Construction research and thus hinder its understanding by newcomers as meanings may change throughout the years. Furthermore, having too many keywords may prevent researchers from recognizing that they are working in similar research areas, so the IGLC community may miss opportunities to collaborate and build upon each other's work.

For example, our analysis revealed that for the 1,710 total keywords, IGLC papers from 2000-2006 listed:

- 738 keywords only once (43.2% of all keywords)
- 130 keywords only twice (15.2% of all keywords)
- 37 keywords only three times (6.5% of all keywords)
- 71 keywords four or more times (35.1% of all keywords)

Figure 2 and Table 2 outline the instances of keywords in more detail. If we consider keywords that were listed only once of twice, they make up 58.4% of all keywords listed from 2000-2006. Thus, introducing a list of suggested keywords can help streamline the IGLC community's efforts in categorizing papers for fellow researchers.

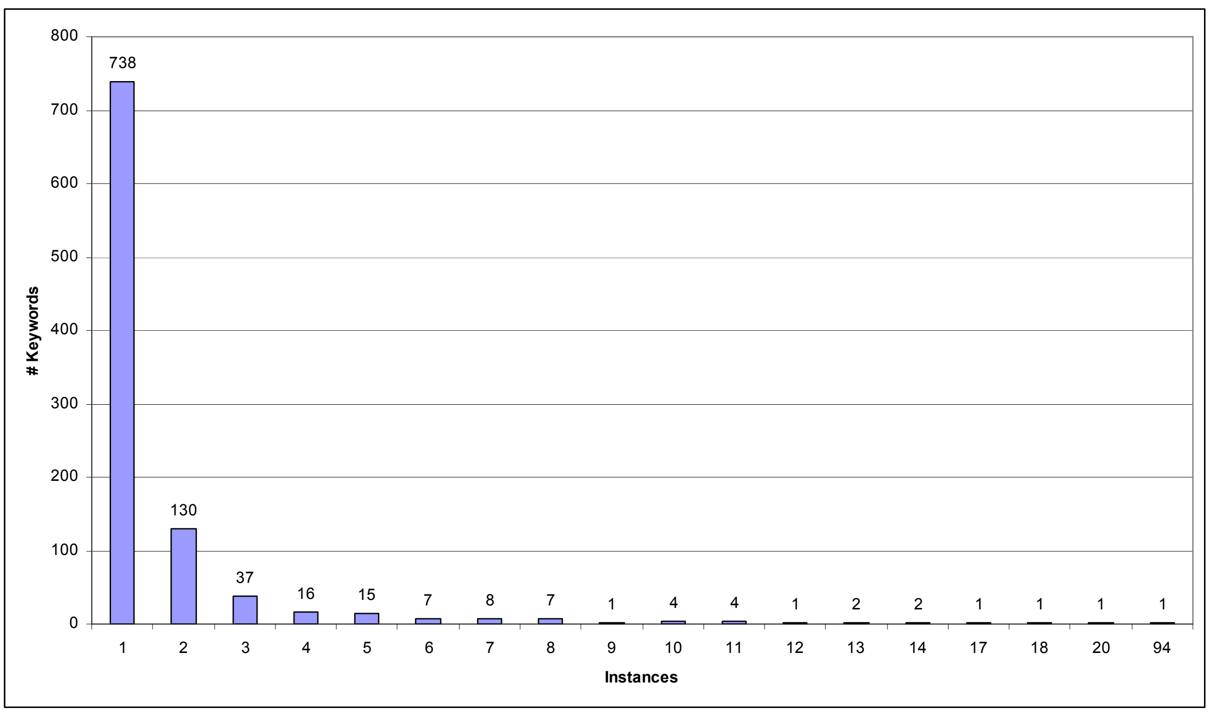

Figure 2: Instances of IGLC Keywords, 2000-2006

Table 2: Keywords in 2000-2006 IGLC Papers with 10 or More Instances

KEYWORD	INSTANCES
lean construction	94
supply chain management	20
project management	18
construction	17
last planner	14
lean production	14
implementation	13
value	13
scheduling	12
complexity	11
performance measurement	11
production control	11
production management	11
design management	10
value generation	10
waste	10
work structuring	10

The findings presented in this paper can begin to help authors better define the keywords for their IGLC and Lean Construction Journal papers, as well as other venues that publish Lean Construction research. This paper may also help the IGLC community by starting the development of a Lean Construction Lexicon which standardizes meanings and facilitates dialogue between researchers from different countries and backgrounds. This would be in addition to the Lean Construction Institute's efforts to define meanings for Lean Construction words and terms listed in the glossary section of their website (see LCI 2006).

This paper is just the starting point for the discussion on keyword clustering. Future work should investigate and propose better methods of classification. Furthermore, while we do not advocate preventing authors from introducing new keywords, we recommend that the IGLC community begin developing a list of recommended keywords. Having standardized keywords reduces the proliferation of keyword variations. The IGLC community might also consider asking authors to identify which parts of the LPDS they are addressing in their papers. Standardizing keywords and binning papers against the LPDS can improve alignment between researchers by increasing the likelihood of research exchange and the development of new collaborative relationships between international researchers. This would then strengthen the IGLC community and the Lean Construction community at-large and mobilize our efforts as academics and practitioners to transform the AEC industry.

Acknowledgments

The Authors would like to thank the IGLC community for making the majority of their conference papers available free of charge at www.iglc.net. The Authors would also like to thank LCJ editors Tariq Abdelhamid and Alan Mossman and the reviewers of this paper for their valuable feedback on our work.

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Appendix – Composition of Keyword Clusters

client / customer

- client
- client involvement
- client requirements
- client requirements management
- customer
- customer lead-time
- customer needs
- customer needs analysis
- customer purpose
- customer satisfaction

complexity

- complex dynamic systems
- complex projects
- complex systems
- process complexity
- product complexity
- stakeholder complexity

construction

- construction management

cost

- activity based costing and management
- activity-based costing
- activity-based costing (ABC)
- cash flow
- construction cost
- construction overhead costs
- cost control
- cost forecasting
- cost information
- cost management
- cost performance
- cost reduction
- designing to target cost
- kaizen costing
- poor quality costs
- poor-quality costing
- profit point analysis (PPA)
- project financial management
- resource-based costing
- return on investment
- target cost
- target costing
- transaction cost economics
- transaction costs analytical modeling

culture and human aspects

- behavior
- behavioral development
- behaviour model
- change
- change management
- changed organisational structure
- cognition
- cognitive engineering
- cognitive systems engineering
- collaborative work
- collaborative working environments
- construction culture
- cultural barriers
- culture and subculture
- culture of quality
- design sociology
- education
- field personnel
- HRM
- human behavior
- human centered focus
- human error
- human resource development
- human resource management
- incentive
- lean leadership behavior
- lean transformation policy deployment
- learning organization
- learning region
- middle manager role
- motivation
- organisational change
- organisational learning
- organization
- organization development
- organizational change
- organizational culture
- organizational learning
- project culture
- quality and change management
- worker's evaluation

design management

- briefing
- concurrent design
- concurrent design and construction
- concurrent design for production
- dependency structure matrix
- DePlan
- design
- design and documentation quality
- design brief
- design concept
- design coordination
- design criteria
- design criteria change
- design dictionary
- design fixity
- design for maintenance
- design for production and constructability
- design intent document
- design postponement
- design process
- design quality
- design rationale systems
- design review
- design rework
- designing
- detail design
- detailed design
- early design
- engineering design
- information-based design dependency matrix
- key design parameter
- lean design
- lean design management
- predesign
- product design
- product development process
- resource planning
- resource-driven scheduling
- set-based design

implementation

- project implementation
- strategies of implementation
- systemic implementation

information technology
- 3D / 4D CAD
- 3D modeling
- 4D CAD modelling
- 4D visualization
- bar-code technology
- computer aided design (CAD)
- computer integration
- computer simulation
- computer tools
- construction simulation
- digital fabrication
- digital prototypes
- fuzzy logic
- GPS system
- Internet
- IT
- java
- knowledge discovery in databases (KDD)
- mobile phone
- networking simulation
- neural network
- process simulation
- simulation model
- simulation modeling
- simulation optimization
- virtual reality

last planner
- commitment planning
- commitments management
- first-run study
- Last Planner Method
- last planner methodology
- last planner system
- lookahead plan
- lookahead planning
- percent plan complete
- percent plan complete (PPC)
- phase planning
- PPC
- the last planner system
- weekly work plan
- weekly work planning

lean construction

lean production

performance measurement
- benchmarking
- construction performance measures
- construction process benchmarking
- performance indicators
- performance measurements
- performance metrics
- performance tracking
- qualitative benchmarking

preassembly / prefabrication
- assembly
- assembly package
- disassembly
- fabrication
- fabrication shop
- lean prefabrication
- off-site fabrication
- off-site manufacturing
- preassembly
- pre-assembly
- precast fabrication
- prefabrication
- pre-fabrication
- volume element prefabrication

production management
- production control
- production improvement
- production planning
- production planning and control
- production/operations management
- project production
- project production system

project management
- project and planning control
- project control
- project controls
- project organization
- project planning

quality
- internal quality audits
- quality assignment
- quality assurance
- quality control
- quality management
- quality management systems
- total quality management

safety
- accident
- accident theory
- boundaries
- construction safety
- hazard
- hazard identification
- macroergonomics
- occupational ergonomics
- occupational safety
- safety in construction
- safety management
- safety training
- working conditions

scheduling
- coordination
- CPM
- CPM as product
- cross-functional teams
- distributed scheduling
- float management
- flowline
- line of balance
- line-of-balance
- multi-diciplinary team
- multi-skilled workers
- multiskilling
- multi-tasking
- planning
- planning and control
- planning system
- repetitive scheduling
- schedule planning

supply chain management
- construction supply chain management
- construction supply chains
- logistic centers
- logistics
- logistics planning
- supply chain
- supply chain analysis
- supply chain integration
- supply chain management in construction
- supply chain mapping
- supply chain strategies
- supply chains
- total supply chain

value
- chain of value for clients
- customer value
- value based management
- value chain
- value chain management
- value creation
- value generation
- value loss
- value management
- value parameters
- value stream
- value stream analysis
- value stream mapping
- value stream maps
- value-added time
- value-based management
- value-stream mapping

waste
- materials waste
- time waste
- waste causes
- waste control
- waste rates
- waste time
- wastes

work structuring