Lean Construction – 2000 to 2006

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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:

- Common root words: 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.
- Related words: 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:

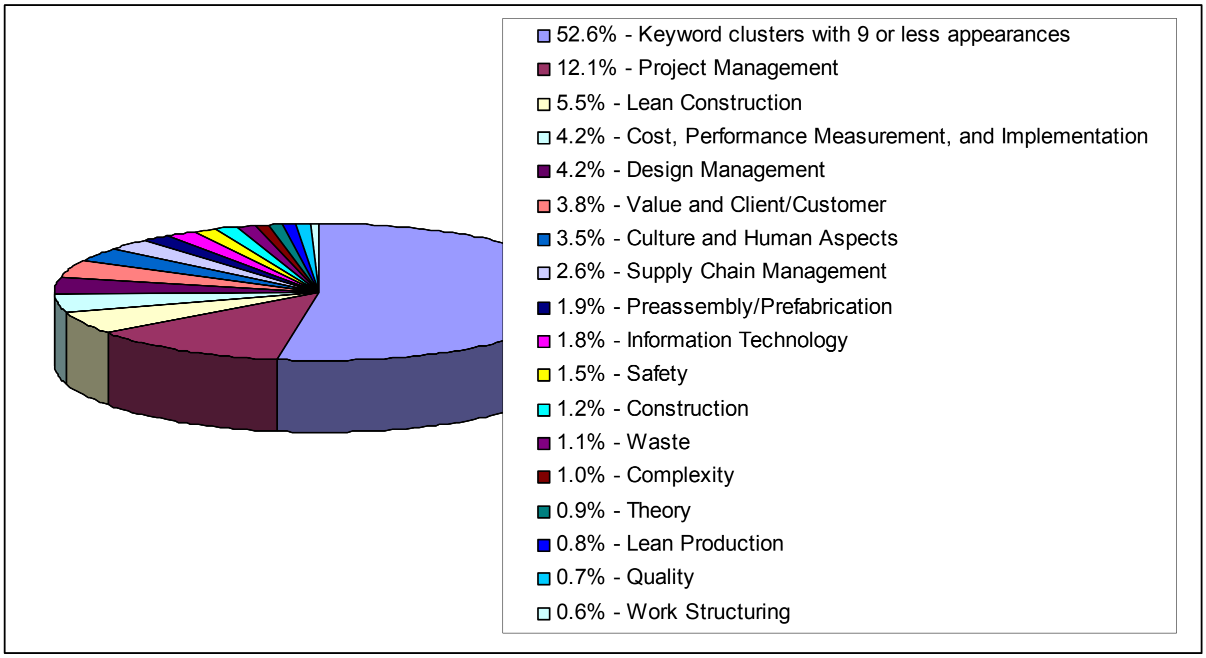

Figure 1: Keyword Clusters and their % Contribution to all IGLC Keywords, 2000-2006

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.

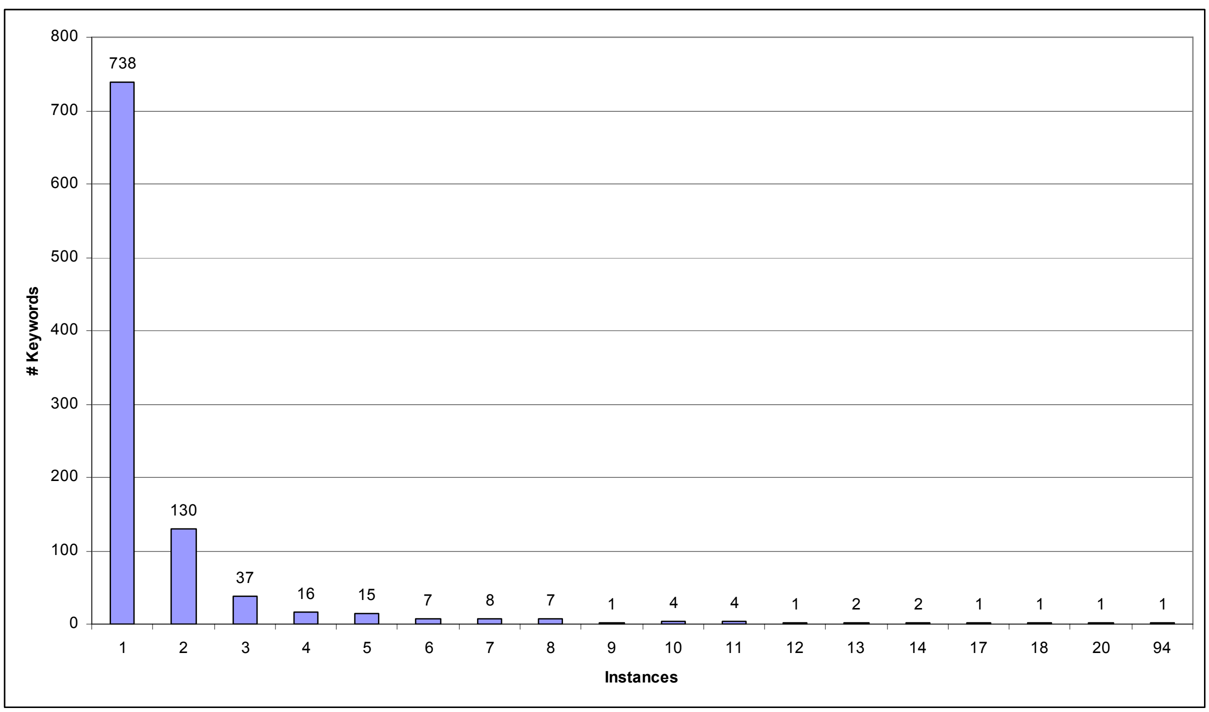

Figure 2: Instances of IGLC Keywords, 2000-2006

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.

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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