DISSERTATION

REVIEW OF LEAN CONSTRUCTION CONFERENCE PROCEEDINGS AND RELATIONSHIP TO THE TOYOTA PRODUCTION SYSTEM FRAMEWORK

Submitted by

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WE HEREBY RECOMMEND THAT THE DISSERTATION PREPARED UNDER OUR SUPERVISION BY GIDEON FRANCOIS JACOBS ENTITLED REVIEW OF LEAN CONSTRUCTION CONFERENCE PROCEEDINGS AND RELATIONSHIP TO THE TOYOTA PRODUCTION SYSTEM FRAMEWORK BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY.

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ABSTRACT OF DISSERTATION

REVIEW OF LEAN CONSTRUCTION CONFERENCE PROCEEDINGS AND RELATIONSHIP TO THE TOYOTA PRODUCTION SYSTEM FRAMEWORK

The objective of this study was to align the International Group of Lean Construction (IGLC) conference proceedings against the Toyota Production System (TPS) to determine how well research themes in construction studies align with the TPS framework. Factories around the world that have implemented the TPS framework have experienced impressive production outcomes. Content analysis was chosen as the methodology in conducting the study of IGLC conference proceedings from 1996 through 2009. A total of 592 IGLC research studies were analyzed. The analysis revealed that lean research in construction did not align exclusively around the TPS framework. From 592 studies, 241 (40%) were classified within the four overarching TPS categories having the 14 TPS principles; 351 (60%) were classified outside the framework as fitting in one of 15 other important proxy lean related research categories. The findings were reflective of IGLC research studies between 1996 and 2009 and did not reflect lean research contributions outside this database. This study has particular implications in knowledge, practice, and teaching. Lean researchers are encouraged not to confine their research to a specific construction sector but rather conform to a broader research platform including the building, heavy, and civil engineering sectors so that these sectors can benefit from future lean research. Critical discussion on the preconditions for, and limits of, lean research initiatives promise to contribute to a stronger body of lean knowledge in the industry concerned with developing the built environment.

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CHAPTER ONE: INTRODUCTION

Introduction

After World War II, Japan had to rebuild its infrastructure and manufacturing capacity which was devastated during the war. During that time the U.S. introduced mass production and quality theory to Japan, based on success in the U.S., in an effort to help Japan recover from the war and rebuild its economy. The manufacturing process that grew out of that has come to be known as Lean Production, which has become the global standard in manufacturing. In contrast, the construction industry has lagged well behind similar productivity improvements (Marosszeky & Karim, 1997). It is estimated that the construction industry lags some 10 years behind in productivity improvement measures (Marosszeky & Karim). It is essential to realize that productivity improvements are needed to maintain market share in the face of intense global competition (Fowler, 1997). The importance of such competition and how it relates to construction is imbedded in the fact that construction activity in most countries accounts for 10% of the Gross National Product (GNP) (Green, 1999). In some European countries, such as Denmark, it is as high as 25% (Green).

Construction is viewed as a specialized application of manufacturing in a complex and variable environment (Marosszeky & Karim). This has led to the realization that management and technical innovations in lean production have direct relevance for construction (Koskela, 1992). For this reason valid comparisons can be made between the construction industry and the manufacturing industry in order to enable the former to develop from the knowledge of the latter in a drive towards improved productivity (Koskela, 1994). This realization has led to the coining of the term "lean construction" for improving productivity in construction. Improvements include a higher quality output, a reduction of costs, a better process for the client, and improved working conditions and safety for employees (Murray, 2003). To a growing group within the construction industry, lean construction seems to be the best way to reach these goals (Horman & Kenley, 1996; Howell & Ballard, 1998; Isatto & Formoso, 1998; Martin & Formoso, 1998; Santos, Formoso, & Hinks, 1996). Furthermore, according to Green (1999),

> The concept of lean production consists of a complex cocktail of ideas including continuous improvement, flattened organization structures, teamwork, the elimination of waste, efficient use of resources and co-operative supply chain management. (p. 23)

The essence of this study is to evaluate how well lean research in construction over the last 14 years aligned itself with the theoretical framework as put forth in *The Toyota Way* (Liker, 2004).

Organization of Dissertation

This chapter provides an introduction to the dissertation. Readers will find the motivation leading to the problem statement, purpose of the research, an overview of the conceptual and theoretical framework, outline of the research questions, delimitations, assumptions, and a personal reflection by the researcher on the intent of this study. Chapter Two serves as a review of the literature on the development of lean construction in light of borrowed production and quality theories over time. Readers are introduced to major production and quality theories as they relate to lean construction. Chapter Two concludes with a summary of how the study adds to the body of lean construction research and benefits the construction industry as a whole. Chapter Three provides readers with a synopsis of the research methodology as it relates to the study. Chapter Three further guides readers through a four-step process as it relates to the analysis section of the study. Chapter Three concludes with an overview of reliability and validity measures in support of the study outcomes. In Chapter Four readers will find the results based on the qualitative analysis conducted in the study, supported by a series of research tables as they relate to the research questions in the study. Chapter Five closes the dissertation with conclusions derived from the research findings. Readers will also find the researcher's recommendations for future research in lean construction.

Background

The following four sections, namely, general production, lean production, construction operating platform, and lean construction, will provide the reader with an overview of the background of the development of lean over time, as applied to construction.

General Production

In theory, production can be divided into three categories as listed in Table 1. These categories include craft, mass production, and lean, which are all viewed as production segments with different processes and outcomes based on their distinct and diverse operating platforms (Mossman, 2009).

Table 1.

Three Types of Production Systems

Functions	Craft Production	Mass Production	Lean Production
Focus	Task	Product	Customer
Operations	Single Item	Batch and Queue	Synchronized flow and pull
Overall Aim	Mastery of Craft	Reduce cost and increase efficiency	Eliminate waste and add value
Quality	Integration (part of the craft)	Inspection (a second stage after production)	Prevention (built in by design and method)
Business Strategy	Customization	Economies of scale and automation	Flexibility and adaptability
Improvement	Master-Driven (continues improvement)	Expert driven periodic improvement	Workforce driven continued improvement

Craft Production. Craft production is known as the oldest form of production. This production phenomenon can be viewed as a method of producing goods by hand with or without the utilization of tools or equipment. This production method dates back to manufacturing during the pre-industrialized world. An example of craft production is the manufacturing of pottery by hand. One characteristic of craft production is that the end product is tailored to the specific need required. Womack, Jones, and Roos (1990), in the book, *The Machine That Changed the World,* discussed the notion that automobiles in the early century were produced based on craft manufacturing techniques. The operational platform associated with craft production is based on producing a single item, one at a time, with a very high mastery of customization. Craft production paved the way for mass production.

Mass Production. Mass production is the method of producing standardized products on a larger scale, mostly in an assembly line fashion. Mass production utilizes powered moving units to move products to workers on a conveyer production line. Mass production is a capital intensive process with a lower labor and higher production cost than craft production. In mass production proficiency belongs to process flow and not to individualized skill as is the case with craft production. In mass production each worker performs a series of different tasks on a continuous basis. For this reason, time taken to manufacture products is shorter when compared to craft production. Mass production also has a lower variability in human error and is inflexible in design changes based on the high cost associated with linear product manufacturing. Mass customization can be viewed as a subcategory of mass production, which can be applied in both traditional manufacturing as well as in production environments like construction.

Lean Production. Lean production is focused on resource utilization and value creation for the end user or customer. The essence of lean production centers on creating more value with better efficiencies. In lean, waste is referred to as "muda." Liker and Meier (2007) broke down the different waste factors in lean production:

1. Overproduction: Producing items for which there are no immediate orders.
2. Waiting (time on hand): Where workers watch an automated machine or have to stand around waiting for the next processing phase.
3. Unnecessary transport or conveyance: Where workers have to carry work over long distances adding to the time factor of production.
4. Over processing or incorrect processing: Where workers take unneeded steps to process parts or functions.

5. Excess inventory: The accumulation of excess inventory in the form of raw materials or finished goods.
6. Unnecessary movement: Includes any wasted motion employees have to perform during the course of their shift, which includes looking for tools and unnecessary walking.
7. Defects: Where workers have to allocate time for correcting defective parts.
8. Unused employee creativity: Losing out on production opportunities by not engaging or listening to employees.

The above waste processes must be supported by lean thinking (Liker & Meier, 2007) and implementation or success varies. Lean researchers in construction take it for granted that lean production in construction is a good thing (Andery, Carvalo, & Helmanl, 1998; Green, 1999; Smook, Melles, & Welling, 1996;). They further state that others argue that lean construction is only concerned with the most efficient means of achieving a given end, meaning that construction companies are simply focused on financial outcomes. Finally, Green (1999) supports the notion that economic externalities—such as traffic congestion, pollution, and the human cost of lean methods—consistently fall outside the adopted lean framework.

History of Lean Production

Lean production is the phenomenon of bringing back or exceeding the quality of early craft production while at the same time providing remedies to the inefficiencies of mass production (Liker & Meier, 2007). The lean operations management design approach focuses on the elimination of waste and excess from tactical product flows; it represents an alternative model to that of capital-intense mass production (Huntzinger, 2007).

Lean production evolved on the shop floors of Japanese manufacturers and, in particular, innovations at the Toyota Motor Corporation. The concept of the Toyota Production System (TPS) today referred to as “lean,” developed due to certain distinguishing features characteristic of Japan. The most distinctive feature was the lack of natural resources, which made it necessary for the Japanese to import vast amounts of materials. For this reason Japan was at a disadvantage in terms of the cost of raw materials when compared to the European and American countries (Sugimori, Kusunoki, Cho, & Uchikawa, 1977). To overcome this, it was essential for Japanese industries to put forth their best efforts in order to produce better quality goods that had higher added value at an even lower production cost than those of other countries (Sugimori et al., 1977). A second distinctive feature was the Japanese concept of work, a concept that incorporated conscientiousness and attitude. This concept was different from European and American workers’ work concepts (Sugimori et al., 1977).

The Japanese also possess distinctive cultural traits: (a) a group consciousness, or a sense of equality, desire to improve, and diligence born from a long history of a homogeneous race; (b) a high degree of ability resulting from higher education, brought about by desire to improve; and (c) daily living centered around work (Sugimori et al., 1977). This combination of distinctive features and cultural traits has aided Japan in the application of lean principles (Sugimori et al., 1977) .

Sparked by the superior performance achieved by lean producers over the performance of traditional mass production system designs, Western manufacturers began to emulate the shop floor techniques—the structural parts of lean—but often found it difficult to introduce the lean organizational culture and mindset (Womack et al., 1990). For industries to make full use of the Japanese lean advantage it was important that industries have their workers display their capabilities to the utmost (Sugimori et al., 1977). Many early lean efforts showed localized impacts only, and fell short of their intended impact on the overall system's performance (Holweg & Pil, 2001).

Lean production has evolved over time, and will continue to do so. As a result of ongoing development, significant confusion about what is and is not lean has arisen. This confusion is clearly observable at both academic and industry conferences (Womack et al., 1990). Many believe that the current debate around lean construction is based on a highly selective interpretation of available literature (Green, 1999). Green suggests that limited research has been directed at construction factors that lie beyond the narrow scope of production improvement: "Lean research studies have been partially contributed to a skewed perception of the Toyota Production System (TPS) in construction lean research" (Green, 1999, p. 21).

Lean The successful implementation of lean in the construction sector will require a change of mindset, the development of a lean culture, and implementation processes to sustain lean over time. Lean is a process that must be developed over time, not implemented overnight; lean should be viewed as a unique paradigm serving the needs of any industry (Womack et al., 1990). Lean goes well beyond the construction platform.

Therefore, considering the assertion that there has been limited research about lean in construction, and considering the argument that lean matured within manufacturing which has a different platform than construction, the construction industry has a need to research the application of lean in construction. As Green (1999) stated,

> The primary concern of construction academics should be the development of the industry's intellectual capital. The promotion of thoughtfulness and critical reflection has been neglected for far too long. The articulation of a critical perspective on lean construction provides a small step towards correcting the current imbalance. (p. 23)

Construction Operating Platform

Over the last decade companies in the construction industry have attempted to emulate the TPS framework in a quest for greater profitability. However, there is great debate about the difference between the manufacturing and construction operating platforms and how these differences may limit lean applicability to the construction operating platform. Some have suggested that there are four features that differentiate the construction operating platform from that of manufacturing: site production, project uniqueness, complexity, and uncertainty (Koskela & Vrijhoef, 2000). These features support the notion of why all lean principles are not amendable to the construction operating platform when compared to manufacturing operating platform. These four features, which are deeply imbedded within the construction operating platform, are expanded upon as follows.

- Site Production: The production for manufactured goods is location specific. In construction, production is site specific, which means it is contoured around the nature of the product (Paez, Salem, Solomon, & Genaidy, 2005), although off-site and modular production in construction cannot be fully classified as location specific.
- Project Uniqueness: Refers to a product made on-site in construction and where customers can modify the scope and details of the product by addenda

(Paez et al., 2005). However, on-site addenda modifications in construction are not favored due to added or increased cost.

- Complexity: In construction, the installation of sub-assemblies is constrained by interacting and overlapping activities performed by different contractors (Paez et al., 2005). Similar complexity exists in manufacturing where products are manufactured and delivered by different supply contractors.
- Uncertainty: Unavoidable uncertainty exists in construction throughout the duration of a project. Such uncertainties include weather conditions, soil conditions, owner changes, and the interaction between independent operations (Paez et al., 2005). However, this statement by Paez does not truly differentiate construction from manufacturing uncertainties because project duration, weather conditions, soil conditions, and owner changes can be viewed as manageable variables in construction.

Lean in Construction

Site production, project uniqueness, complexity, and uncertainty all deliver challenges to the construction industry in an attempt towards lean implementation as explained in the following.

- Site production in construction introduces the following temporary infrastructure variables: transportation access including pathways to and from sites; utility access in terms of electricity, water access, and drainage; theft prevention measures due to remote or less secure locations; and material storage provisions (Paez et al., 2005).

- Project uniqueness in construction calls for relationships among owners, general contractors, and various special trade contractors. All contracts between these players are based on the plans and specifications, which describe the project, its location and characteristics, methods of construction to be used, standards and performance tests that must be met, raw materials, and suppliers to be used in completing the project. However, these specific specifications can change and often do, which Paez et al. (2005) refer to as a project unique characteristic associated with construction.
- Complexity in construction involves the use of specialty trade contractors, which are construction workers that perform the work of only one trade, such as painting, carpeting, plumbing, or heating. Complexity in construction refers to the need to schedule the work of these trade groups, which are viewed as independent contractors, and who have to fit their work to that of other trades. This is in contrast to the assembly line manufacturing process. Specialty trade contractors have no responsibility for the project as a whole, which adds to the difficulty of scheduling the installation of sub-assemblies in construction (Paez et al., 2005).
- Construction uncertainties are dealt with on a daily basis in the industry. The following list of examples of uncertainties includes improper design, wrong specifications, inaccurate project cost, delayed supplies of materials, unskilled and inexperienced workers, and fluctuating material cost during the duration of the project. Clients demanding that projects be completed on short duration

add to the list of unavoidable uncertainties associated with the construction operating platform.

Lean production can be viewed as a model where each step of activity has been built on the foundations of craft and mass production (Mossman, 2009). Implementing lean processes in project-based organizations like construction companies are likely to take longer than in manufacturing, where it often takes three to five years just to embed a continual improvement culture (Mossman, 2009). Succinct alignment of the TPS framework in the construction industry is an ongoing challenge based on the fact that by definition, construction is not classified as a mass production industry like manufacturing, but rather as a project based industry where projects are unique based on their design and purpose (Mossman, 2009).

After 1990, the drive for lean in construction accelerated. Western industries in diverse sectors that had adapted their production systems to include new lean design began to promote their success (Womack & Jones, 1996). These successes involved identifying customer value, managing the value stream, developing the capability to flow production, using "pull" mechanisms to support flow of materials at constrained operations, and finally, pursuing perfection by reducing to zero all forms of waste in the production system (Womack et al., 1990). In construction, lean success has been measured through examples of the following contributions to the field.

- *The Last Planner* (a project delivery model) has significantly contributed to lean outcomes in construction since its inception in 1992. This project delivery model was inspired by the TPS model (Ballard, 1997). Implementation of the *Last Planner* in construction has yielded many benefits such as cost saving and completing projects on time (Ballard, Castem, & Howell, 1999; Ballard, 1997; Fiallo & Rovelo, 2002).

- Design Management in construction refers to the integration of construction design into management and vice versa. The benefits of design management integration in construction have proven to benefit the industry through reduced cost and shorter production times. (Codinhato, Tzortzopoulus, Rooke, & Kagtioglou, 2008; Mesquita, Fabricio & Melhado, 2002; Shimizu & Cardoso, 2002).

Problem Statement

Toyota employs the Toyota Production System (TPS) as the single guiding production principle in their factories across the world (Liker, 2004). The omission of any of the TPS principles would alter desired outcomes for Toyota. The International Group of Lean Construction (IGLC) was formed in 1993. The IGLC vision statement includes "to better meet customer demands and dramatically improve the Architect, Engineering and Construction (AEC) process as well as product" (International Group of Lean Construction [IGLC], 2010). Their vision speaks to the perceived need for lean research in construction related industries. IGLC focuses its attempts on lean construction research and contributions by researchers across the world. Past research studies have partially contributed to a skewed perception of lean in construction (Green, 1999). The problem is that there have been few, if any, empirical research studies that have examined the existing lean construction literature in relation to the TPS framework which is viewed as the underpinning of lean. Deviating from the TPS framework in research can lead to a skewed perception of lean in construction. Understanding how existing literature aligns with the TPS framework will help direct future lean research initiatives which then will contribute to the application of this research to the larger lean construction operating platform.

Purpose of the Study

The essence of this study centered on the importance of a grounded lean research platform in relation to the TPS framework in construction. This was accomplished through content analysis to describe trends in communication content and reveal the focus of the group IGLC. The purpose of this study was to foster awareness of lean research in construction and to determine how lean research studies, as published in peer-reviewed IGLC conference proceedings between 1996 and 2009, align to the TPS theoretical framework. Critical discussion on the preconditions for, and limits of, a lean research platform in construction would greatly contribute to a stronger body of lean knowledge in the built environment.

Research Questions

The objective of this study was to compare past lean research studies in construction to the TPS theoretical framework. The TPS framework consists of the following four overarching categories: Long Term Philosophy, consisting of one lean principle; The Right Process, consisting of seven lean principles; People and Partners, consisting of three lean principles; followed by Problem Solving, consisting of three lean principles, as put forth in *The Toyota Way* (Liker, 2004). This outline is displayed in Figure 1.

TPS Theoretical Framework Outline

A. Long Term Philosophy

1 Base every management decision on long term philosophies

B. The Right Process

2 Create process flow
3 Employ a pull system
4 Level out the work through appropriate scheduling
5 Create a culture capable of stopping and fixing problems as they surface
6 Standardize tasks
7 Use vision control
8 Use tested technology

C. People and Partners

9 Grow leaders
10 Develop exceptional workers
11 Value partner and supplier networks

D. Problem Solving

12 Managers are expected to align themselves with problem solving efforts
13 Base decisions on slow consensus
14 Become a learning organization

Figure 1. TPS Theoretical Framework Outline

An overarching research question with seven sub-questions directed the course of this study.

1. Are IGLC research studies in lean construction representative of the TPS theoretical framework as put forth in *The Toyota Way* (Liker, 2004)?
   - Sub-question one: What percentage of IGLC analyzed research studies are classified within the TPS framework?

- Sub-question two: Of the research studies classified within the TPS framework, what is the distribution of studies into each of the four subcategories?
- Sub-question three: Over the 14 years of IGLC conference research studies, what is the trend of contribution in each of the four TPS subcategories?
- Sub-question four: What lean related research categories within a percentage breakdown structure emerged from the IGLC conference research studies between 1996 and 2009?
- Sub-question five: What were the research trends between 1996 and 2009 within these lean related research categories?
- Sub-question six: What research methods were used in IGLC research studies between 1996 and 2009?
- Sub-question seven: What has been the level of contribution of different countries to IGLC research studies from 1996 to 2009?

Conceptual and Theoretical Framework

The design of a research study begins with the selection of a topic and a paradigm. A paradigm is essentially a worldview—a framework of beliefs, values, and methods within which research takes place. It is vital for the purpose of this study to fully understand the philosophical underpinning of the research framework, which consists of: ontology, epistemology, and axiology. Figure 2 illustrates how these building blocks work together in supporting thought and practice as it pertains to inquiry.

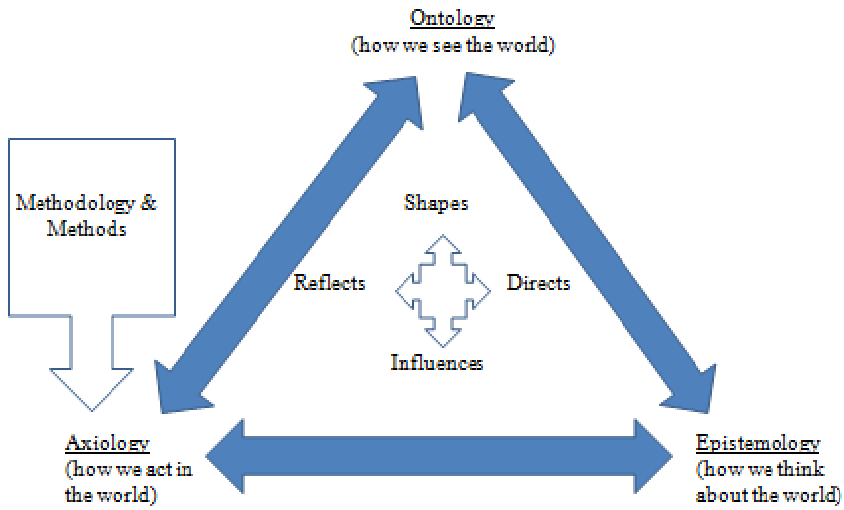


Figure 2. Research Philosophical Framework (Ruons & Lynham, 2004).

In order to better understand the interaction between these forces, the study will investigate each framework segment individually from a philosophical perspective. Ontology is concerned with fundamental assumptions about the nature of phenomena (Gioia & Pitre, 1990). It focuses on basic questions and assumptions about the nature of reality. Epistemology, also described as theory of knowledge, is the component of philosophy that raises questions about the nature of knowledge and reasonable belief. Gioia and Pitre (1990) describe epistemology as fundamental assumptions about the nature of knowledge about phenomena. Axiology, sometimes referred to as ethics, is concerned with action. It is normative, speaking to issues of what is good and what ought to be done. In other words, it indicates how one should act in inquiry and practice (Denzin, 2009). Methodology is defined as the system that influences the way things are done—that is, how researchers choose and use methods, conceptualize phenomena, analyze and collect data, and design interventions (Lincoln & Denzin, 2003). Methods on the other hand, are means and manners of procedure. Due to the applied nature of construction, methodologies and methods need to be considered in the context of both research and practice (Gioia & Pitre, 1990).

In the humanities and social sciences, which include construction, the underpinnings of inquiry are supported by positivist, post-positivist, critical, constructivist, and participatory theories. This study is embedded within the constructivist theory paradigm based on the philosophical underpinning of its inquiry design. The constructivist paradigm is a philosophy of learning, based on the premise that reflecting on experience, the researcher constructs understanding of the surrounding world. This paradigm searches for meaning, meaning that requires understanding the whole as well as its parts. The parts must be understood in the context of the whole. The essence surrounding this paradigm focuses on primary concepts rather than isolated facts. In addition, constructivist paradigms can be viewed as socially oriented towards building knowledge in contrast to traditional theory, which is geared only to understanding or explaining a phenomenon. The constructivist paradigm supports the intent of this study for the reason that constructivism is building on existing knowledge. In addition, the constructivist paradigm focuses on the analysis of texts and text-like phenomena, which in this case are the IGLC conference proceedings. Table 2 explains the constructivist paradigm framework as it relates to this study from a philosophical perspective.

Table 2.

Constructivist Paradigm Framework as it Relates to this Study

THEMES OF KNOWLEDGE: Inquiry Aims, Ideals, Design, Procedures, and Methods				
	Ontology: It is the study of being	**Epistemology:** It is the study of what is meant by knowledge.	**Methodology:** It is the precise design of a study.	**Axiology:** It focuses on what is good.
	Basic Question: What is the nature of the knowledge– or what is the nature of reality?	**Basic Question:** What is the relationship between the knower and the known?	**Basic Question:** How should the inquirer go about finding out knowledge?	**Basic Question:** What values guide the choice made by the researcher in the selection, conduct, and dissemination of inquiry and its outcomes?
Constructivist Paradigm Believes the only reality we can know is that which is represented by human thought. Learners construct knowledge for themselves – individually and socially as they learn?	**Metaphysics** Put together our own reality. Realities is dependent on the individual or group. Reality exists as a set of holistic and meaning-bounded constructions (Guba, 1990).	**Metaphysics** Findings are based on the relationship between inquirer and inquired. Interaction between researcher and participant is the basis of learning (Guba, 1990).	**Metaphysics** Individual constructions are refined, compared, and contrasted to generate one consensus construction (Guba, 1990).	**Metaphysics** Knowing is instrumentally valuable as a means to social emancipation (Crotty, 2003).

In addition to the philosophical and paradigm design, this study was further framed within the qualitative methodology framework, which can be defined as an inquiry process of understanding a social or human problem. The qualitative framework is based on building a complex, holistic picture; is formed with words; reports detailed views of informants; and is conducted in a natural setting (Creswell, Plano Clark, Gutmann, & Hanson, 2003). Qualitative research can be multi-method in focus—involving an interpretive, naturalistic study of things—by attempting to make sense of or interpret phenomena in terms of the meanings people bring to them (Lincoln & Denzin, 2003). The qualitative nature of this study can further be based on the fact that qualitative methods enable researchers to study social and cultural phenomena (Lincoln & Denzin, 2003).

Definition of Terms

An explanation of the following terms will clarify the reader's understanding associated with forthcoming readings:

- Kiazen: A Japanese word adopted into English referring to a philosophy or a set of practices focused on continuous improvement in manufacturing activities, all business activities, or even all aspects of life, depending on interpretation and usage (Liker & Meier, 2007).
- Muda: A key concept in the Toyota Production System (TPS), Muda is a traditional Japanese term for an activity that is wasteful and does not add value to the process of production (Liker & Meier, 2007).
- Toyota Production System (TPS): An integrated socio-technical system, developed by Toyota, which comprises its management philosophy and practices. TPS organizes manufacturing and logistics for the automobile manufacturer, including interaction with suppliers and customers (Liker & Meier, 2007).

    -- *TPS Principles*: The 14 subcategories within the TPS framework.

    -- *Proxy categories*: Categories created by the researcher outside of the TPS framework to classify studies that could not be categorized within the framework according to the research intent.

- Training Within Industry (TWI): Started and developed to support industry needs in the United States during World War II. It was established in August 1940 by the National Defense Advisory Commission and eventually was moved under the Federal Security Agency (Sugimori et al., 1977).

Delimitations

The study evaluates IGLC conference proceedings between 1996 and 2009. The following delimitations provide the researcher with boundaries within which to conduct the research:

- Time of the study: This research analyzed 14 years of IGLC conference research studies between 1996 and 2009 for contributions to construction lean research. The years 1993, 1994, and 1995 were excluded from the study due to incomplete and inaccessible conference proceedings.
- Database: The database analyzed in this study contains contributions by international researchers. The database specifically catered to lean research in construction. In this way the study focused on a single segment of lean research, namely lean construction, and excluded other lean research segments such as manufacturing.
- Selected aspects of the problem: This study centered on research initiatives and research studies in construction over the last 14 years. Lean construction research embodies many areas of research such as architecture, engineering, and management and covers a wide spectrum of applied applications as it relates to the industry. This study did not dissect any specific lean interest

areas but rather provided an overview of cumulative research contributions by researchers from diverse backgrounds with an interest in lean construction research.

- Analysis software: NVivo, a qualitative analysis software application, was chosen to steer the analysis and organization of the study due to its ability to process large volumes of qualitative data as well as to display the findings in a quantitative arrangement.

Assumptions

Certain assumptions were made in this study, based in part on the method of analysis used. Content analysis was utilized as the chosen methodology based on its ability to utilize a set of procedures in making valid inferences from texts. One important outcome of content analysis is the generation of cultural indicators that point to the state of beliefs, values, ideologies, or other cultural systems (Weber, 1985). Content analysis focuses on empirical studies and seeks to summarize past research by drawing overall conclusions from many separate investigations that address related or identical hypotheses (Weber, 1985). The nature of content analysis pivots around the notion that many words of a text are classified into fewer content categories. There is no simple right way to do content analysis. Instead investigators must judge what methods are appropriate for each study (Weber, 1985). Based on the nature of content analysis, the following four assumptions were made:

1. Literature on lean construction supports the belief that the construction industry functions on an operating platform different from that of manufacturing (Koskela & Vrijhoef, 2000). This platform includes four

features that differentiate it from that of manufacturing: site production, project uniqueness, complexity, and uncertainty.

2. IGLC is representative of lean research as it relates to architecture, engineering, and construction. The IGLC mission statement states the following:

   > *Our goal is to better meet customer demands and dramatically improve the architecture, engineering and construction (AEC) process as well as product. To achieve this, we are developing new principles and methods for the 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, 2010)

3. IGLC best represents lean research as it relates to the construction industry. The following lean research organizations were also considered for this study but did not provide adequate database support: European Group of Lean Construction, Lean Education Academic Network, and Lean Enterprise Institute. Research representation concerning lean applications in construction related fields in other journals was minimal outside of IGLC proceedings. According to Green (1999) the lack of construction research in peer-reviewed journals is currently a weakness in the construction field.

4. The TPS framework used in this study is an accurate representation of the Japanese lean theoretical framework.

Researcher's Perspective

I was raised in a developing economy with a large uneducated population. Quite often in less educated economies people view productivity and quality as less important production commodities. Evidence of this is present around the world. In Asia, the world's most populous region, the biggest problem facing companies is a shortage of skilled labor. Asia has more than half the planet's inhabitants and is home to many of the world's fastest-growing companies. In Asia some organizations are being forced to reconsider how quickly they will be able to grow because they cannot find enough people with the skills they need (Fujiki, Nakada, & Tachibanaki, 2001). It is not only developing economies that experience such an impediment, this analogy is also applicable to first world economies such as South and North America, Europe, and Japan.

A vibrant economy depends on capable infrastructures and intellectual capital. I believe that ways to improve such infrastructures and intellectual capital will greatly benefit humanity as a whole. Succinct operating models are essential in adding value to the bottom line of any culture, organization, or industry. The value of a proven operating model such as the TPS framework should be infused across industries, economies, and countries to enhance production outcomes. Construction across the world continues to shape the physical environment and quality of life of large numbers of people. However, the fragmented nature of its operating platform continues to limit productivity and profitability within the industry. Therefore a need exists in construction to ensure full research representation of the TPS framework as it relates to the construction operating platform. Past lean research studies in construction might have contributed to a skewed perception of the many benefits the TPS framework can deliver to the construction operating platform.

In addition, I enjoyed the opportunity of working in the construction industry for 12 years. During that time I experienced firsthand the struggles construction companies deal with on a daily basis. The last construction organization I worked for was part of an international franchise system. Franchise organizations pride themselves on operating within well established operating models. This company deployed an operating model that was replicated among 220 offices nationwide. The results were phenomenal in terms of profits and productivity. If only an ideal operating model existed for construction companies to function in, the industry would have been much better off.

CHAPTER TWO: REVIEW OF THE LITERATURE

Chapter Overview

The extent to which methods of lean production are applicable beyond the Japanese context in construction remains hotly debated (Green, 1999). The purpose of this chapter is to provide a foundation of knowledge about the development of production theories historically, and how lean today relates to the theoretical underpinning of previous production and quality theories. The evolution of lean is a continuum as explained in the Research and Theory Development Model (Lynham, 2002). Therefore, aligning research studies to the TPS framework in construction will add to greater awareness in the construction industry for a more balanced foundation of knowledge.

In order to discover the value placed on the TPS framework in lean construction research, a review of literature on the history of lean development in construction is essential. The purpose in conducting a review on lean research development in construction is to further link lean research in construction to a larger ongoing dialogue on existing lean literature, filling in gaps and expanding on prior lean studies. Figure 3 illustrates how lean construction evolved over time and also serves as the conceptual map for Chapter Two. As illustrated in Figure 3, lean construction is associated with qualities found in the foundational frameworks of earlier production and quality theories including TWI, Quality Theory, and TPS.

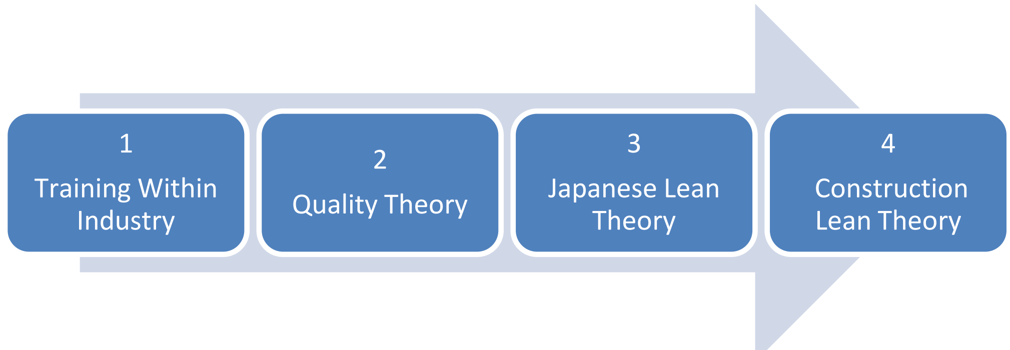


Figure 3. Conceptual Map of Literature Review: Construction lean theory and its connection to earlier production and quality theories.

This chapter establishes the connection between construction lean theory and earlier production and quality theories. Lean theory developed over time and should be viewed as an evolving concept, leading us to believe that lean construction should not be viewed as a short term approach but rather as a long term improvement model. Understanding the connections, similarities, and differences between these different production and quality theories is an important aspect in ensuring the highest profit yield in construction. Productivity theories build on one another as explained in Figure 3, and these theories have allowed the current construction lean theory to evolve.

Literature Review Methodology

The review of literature focused on a sequence of production and quality theories developed over time and how these theories contributed to the theoretical frameworks associated with lean construction today. Construction lean theory shares a mutual foundational framework embedded in production and quality theory as illustrated in Figure 4.

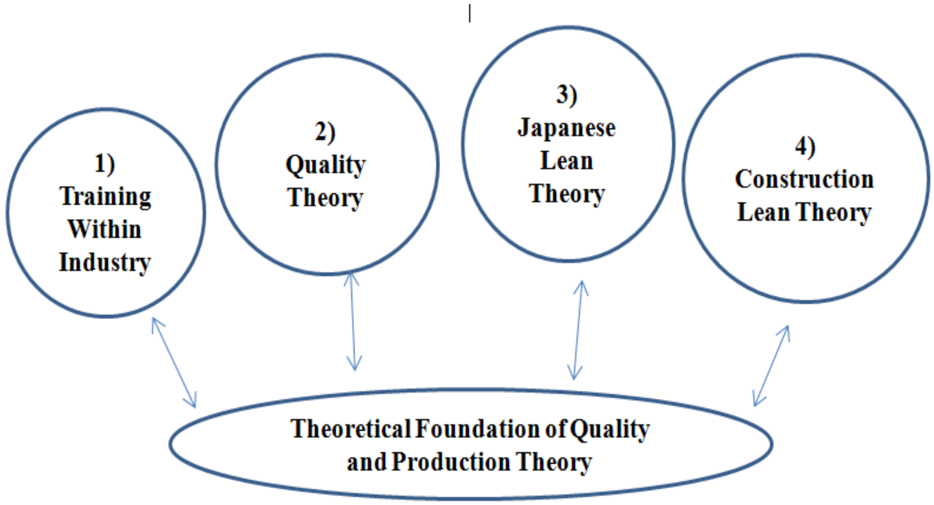


Figure 4. Production and Quality Theories in Construction. An illustration on how early theory frameworks are connected to quality, production, and TPS theories, which are the foundation of lean construction theory.

To develop a full appreciation for the development of lean theory over time and how lean theory relates to construction, it is necessary to understand the connections between the smaller theory circles and the larger theoretical framework illustrated in Figure 4. This literature review looked at each of the smaller framework theories and their links to lean construction. The framework theories included:

- Training Within Industry (TWI): TWI was started and developed to support industry needs in the United States during World War II. The need for greater production output increased production levels in all types of industry. The collection of literature on TWI was found largely in government bulletins, archive collections, and journal articles.
- Quality Theory: It was important to manufacturing companies to establish a framework around the early developments on quality theory and how quality theory relates to TWI. The success of mass production largely depended on quality theory implementation. The review of literature on quality theory

development was conducted through journal articles and books, as well as internet searches.

- Japanese Lean Theory: This production discipline can be viewed as the foundation from which lean construction evolved. In order to develop a full understanding of Japanese lean theory the literature search mainly centered on books on Japanese theory, academic journals, industry journals, and conference proceedings.
- Construction Lean Theory: The essence of this study focuses on construction lean theory; therefore information on current lean trends in the construction industry was central to this literature review. The literature search included lean journal groups, conference proceedings, dissertations, as well as lean construction books.

The next section of the review will focus on the history and development of the four theories and how each theory respectively contributed to the development of lean construction.

Training Within Industry

Training Within Industry (TWI) was an early mass production training methodology employed in the United States during World War II (Figure 5).

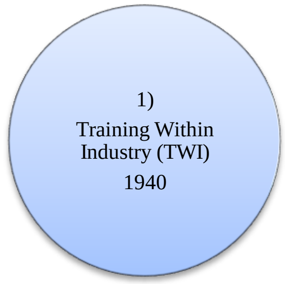


Figure 5. Inception of Training Within Industry (TWI). The first mass training production methodology employed in the United States during World War II.

The structural framework of TWI can be viewed as the underpinning for later production and quality theories. TWI was developed during World War II to help increase war production outputs in the United States. The purpose of TWI can be summed up as follows: to assist war production industries meet their manpower needs by training each worker to make the fullest use of his or her best skill up to the maximum of his or her individual ability, thereby enabling production to keep pace with war demand (Dooley, 2001). During World War II, American defense forces needed significant war supplies. This demand triggered higher production levels across all types of industries. The United States government quickly realized that intervention was needed to help industries keep up with the war time demand for goods and services. Through TWI a nation-wide network of industrial professionals was developed to teach production techniques to manufacturers in the United States (Huntzinger, 2007).

TWI was never forced into any plant, but was introduced by invitation only (Huntzinger, 2007). The creators of TWI recognized and stressed the importance of proper training of workers. They further emphasized how improperly trained employees created excess cost and that the cheapest production method was to use only well-trained people from the start. To achieve the best training within an organizational structure the following four principles were essential: (a) “standards must be set,” (b) “good instruction must be established,” (c) “continued training must be maintained,” and (d) “training must not end too soon” (Huntzinger, 2007, p. 4).

TWI also consisted of three training programs—JI, JM, and JR—frequently called the “J” programs (J stands for “Jobs”). Job Instruction (JI) training taught supervisors how to instruct the people doing the job. This training included explaining to workers why their jobs were important; breaking down the job into logical steps and key points, and teaching the correct method of performing the task; confirming that the workers could do the task on their own; and following up to confirm that standard work was enforced. Today Toyota Motor Company still teaches job instruction in this fashion with little modification to the original design (Huntzinger, 2002).

The Job Methods (JM) program was developed to provide management with a tool whereby supervisors could acquire skills in improving production methods. JM could be described as the Kaizen or continuous improvement component associated with TWI. A key aspect of the JM training program was teaching supervisors how to make the best use of their people, technology, and resources (Huntzinger, 2002).

Job Relations (JR) was a tool to help supervisors acquire leadership skills. This tool recognized that work relationships were an important component of a supervisor’s job and provided instruction about how to address “people” problems, such as morale issues or grievances. Handling personnel issues can be an uncomfortable part of a supervisor’s duty. However, it is known that without the cooperation of the people, not much is going to get done (Huntzinger, 2002). The essence of the JR program centered on four points: (a) get complete facts about a situation, (b) weigh and evaluate the facts, (c) take action, and (d) check the results of those actions.

Finally there was a fourth training model called Program Development (PD). PD was a means of directing companies on how to set up and administer training within their own facility using their own people. PD was developed using input from many experts within each industry to maintain TWI's premise of "for industry by industry." The program development aspect of TWI was essential in dispersing the training programs on a broader scale. The program was also known as a "Multiplier Principle." The multiplier principle was simple in concept, but powerful in its application, because it developed a standard method of training people who would then train other people, who in turn would train groups of people within the company culture (Huntzinger 2002).

TWI had a dramatic impact on organizations during World War II. *The Training Within Industry Report*: *1940-1945* provides many details on the successes of the program. Table 3 is a tabulation of results collected by the War Production Board, Bureau of Training, at seven different intervals during the program deployment.

Table 3

Training Within Industry (TWI) Plant Results

	Percentage of Plants Reporting Results of 25 Percent and Over						
	May-43	Sep-43	Feb-44	Nov-44	Apr-45	Jul-45	Sep-45
Production Increased	37	30	62	76	64	63	86
Training Time Reduced	48	69	79	92	96	95	100
Manpower Saved	11	39	47	73	84	74	88
Scrap Loss Reduced	11	11	53	20	61	66	55
Grievances Reduced	Not reported		55	65	96	0	100

Source: The Training Within Industry Report: 1940-1945 (1945, p. 92)

Based on the success of TWI, the U.S. government introduced the training program to Japan after the end of World War II, translating the TWI training modules into Japanese. During that time the United States government feared a possible outbreak of civil unrest in Japan due to the total destruction of Japan’s infrastructure. The Japanese took advantage of this proven American production model and redefined TWI into what has come to be known as the Japanese lean theory. The success of the Japanese lean production theory is deeply embedded in quality improvement, also known as quality theory. Following is a review of the history and development of quality theory and its contributions to the theoretical framework that supports lean construction today.

Quality Theory

After World War II, mass production became a standard method of producing goods in large volume across the world. The success of mass production was largely attributed to the impact of TWI training during World War II. During that time mass production offered many advantages in terms of high outputs and low production cost. However, the early success of mass production could no longer sustain the lack of quality control. Production organizations realized that the lack of quality control came at a high price. Based on the need for quality control in manufacturing, quality theory became an essential building block associated with mass production.

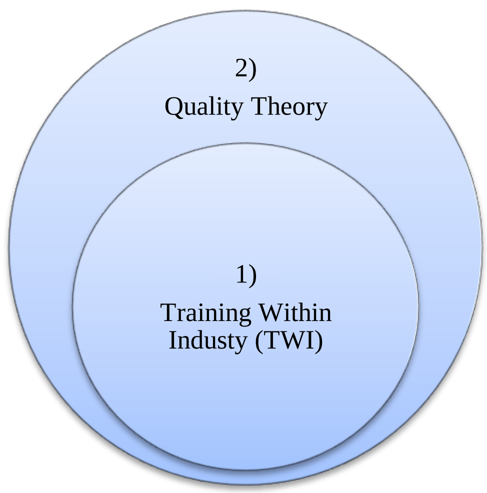


Figure 6. Inception of Quality Theory. Quality theory came to life based on a need to improve quality output in TWI and mass production programs.

The development of quality theory improved production efforts as well as provided a framework for more advanced production theories to follow. According to Lynham (2002), theory should describe and explain how things actually work and, in doing so, help improve actions in the world. The researcher further reviewed the various contributions by early pioneers in the development of quality theory and how quality theory not only enhanced mass production outputs but also created pathways for later production theories including lean construction.

The Pioneers of Quality Theory

During World War II statistical quality control (SQC) entered the production arena as a way to monitor and improve the quality of production output. After World War II, the Japanese economy regained momentum in the production of goods; however, selling their goods internationally was hindered by Japan's poor pre-war reputation for low quality goods. In order to change this perception, the Japanese were determined to learn from other countries how to better manage quality. They visited foreign manufacturing plants and also invited foreign quality theorists such as Joseph Juran, Joseph Deming, and Walter Shewhart to introduce quality theory in Japan. These pioneers played principal roles in how quality theory came to be and how it is applied today. Figure 7 provides a summarized overview of the early pioneers' respective contributions to quality theory development followed by a brief overview on each pioneer and his respective contribution to the theoretical underpinning of quality theory.

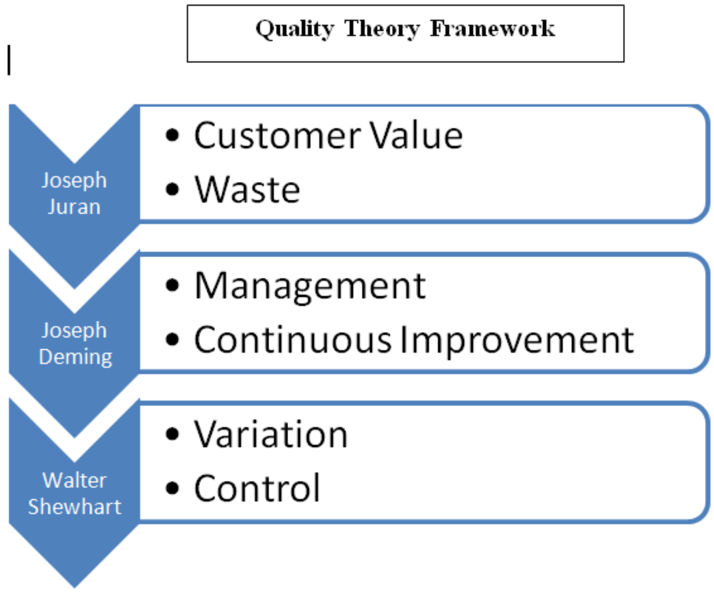


Figure 7. Contributions of Quality Theorists. Quality theorists and their collective contributions to the development of quality theory.

Joseph Juran. Joseph Juran came to be known for his Trilogy Diagram, a method devised to show how to accurately measure for quality. His trilogy diagram consisted of three interrelated concepts: planning, control, and improvement (Juran, 1998). Figure 8 illustrates these sequences in an abbreviated format.

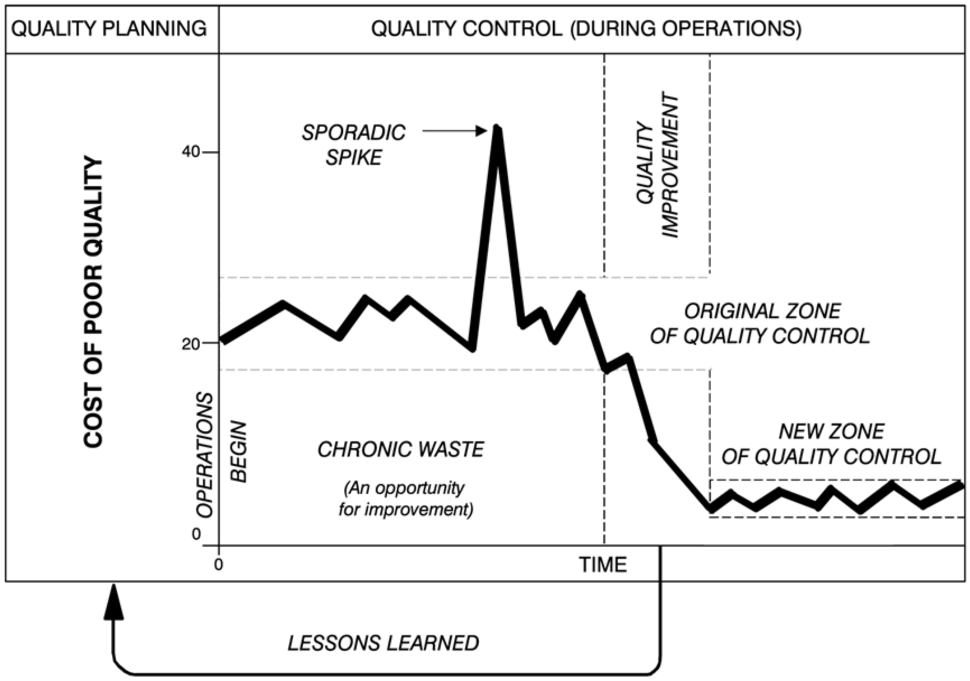


Figure 8. Juran's Trilogy Model Diagram. Illustrates the quality control sequence during operations.

These interrelated quality concepts allow product planners to determine who their customers are and what their needs are. In order to respond to these needs, the product planners determine what methods are appropriate (Juran, 1989). The product planners then turn the plans over to operating authorities to proceed with production. During the manufacturing phase, quality control should receive constant attention. Quality control should be viewed as a constant by monitoring and improving deviation patterns. To attain quality, organizations must establish a vision, policies, and goals within the organization. In order to convert the goals to results, three management processes—quality planning, quality control, and quality improvement—need to direct the process. Table 4 represents an abbreviated outline of Juran's quality model.

Table 4

Juran's Universal Quality Process Model for Managing Quality During Production

Quality Planning	Quality Control	Quality Improvement
Determine who the customers are	Evaluate actual product performance	Establish the infrastructure
Determine the needs of the customers	Compare actual performance to actual goals	Identify the improvement projects
Develop product features that respond to customers' needs	Act on the difference	Establish project teams
Develop processes able to produce the product features		Provide the team with resources, training, and motivation to:
		1) Diagnose the cause 2) Stimulate remedies 3) Establish controls to hold the gains

Juran's trilogy diagram placed emphasis on the importance of creating customer value and reducing waste during production. Juran (1989) further contributed to the development of quality theory by stating that quality theory has universal applicability, for example: (a) in service industries as well as in manufacturing industries, (b) in business processes as well as in manufacturing processes, and (c) in support operations as well as production operations. Juran's contributions to quality theory affirmed that quality in production is associated with an additional cost aspect, adding about 10% to the work load of the management teams overseeing quality improvements (Juran, 1989).

Joseph Deming. Joseph Deming is considered the father of the modern quality movement. The impact of Deming's contributions on quality theory has been profound. Deming identified 14 points in management, which when applied accordingly, improved manufacturing efficiencies. Deming's 14-point management model consists of the following (Deming, 2000):

1. Create constancy of purpose and continual improvement while long term planning must replace short term reaction.
2. Introduce management as well as workers to the Japanese production theory.
3. Do not depend on quality inspection—build quality into the product and process.
4. Choose quality suppliers over low cost suppliers in order to minimize variation in raw material and supply.
5. Improve constantly to reduce variation in all aspects of production.
6. Train workers and management on the job in order to reduce variation in how a job is done.
7. Institute leadership across the organization.
8. Eliminate fear while encouraging two-way communication; encourage employees to work in the organization's interest.
9. Break down internal barriers so that departments in an organization become "internal customers" to each other and must work together.
10. Eliminate slogans (exhortations) on the job site.
11. Eliminate numerical targets; rather, manage by objective.
12. Remove barriers to worker satisfaction; instead include annual appraisals.

13. Encourage self-improvement and education for all workers.
14. Ensure that everyone is responsible for continual improvement in quality and productivity, especially top management.

Deming is perhaps best recognized for his work in Japan, where he taught quality improvements to top management and engineers during the 1950s. His contributions to quality theory dramatically improved the economy of Japan. His 14-point outline highlights the importance of management and continued improvement in production and manufacturing.

Walter Shewhart. The work of Walter Shewhart focused on the importance of reducing variation in a manufacturing process. Shewhart proposed that continuous process-adjustment in reaction to non-conformance actually increased variation outcomes and degraded quality (Shewhart, 1980). Shewhart believed that statistical theory was part of manufacturing. He further believed that the lack of information in manufacturing and production greatly hampered production outcomes. Shewhart (1980) created the “Cycle, Learning and Improvement Model,” which combines creative management thinking with statistics. The model incorporates the following steps—Plan, Do, Study, and Act—and draws its structure from the notion that constant evaluation of management practices, as well as the willingness of management to adopt and disregard unsupported ideas, are key to the evolution of any successful production or manufacturing outcomes.

Shewhart’s variation model is relevant in production where variation is viewed as a constant (Wheeler, 2007). For example, if you cut a diamond, a slight slip of the hand can be expensive. In production it is important to address events of variation as soon as they occur (Shewhart, 1980). The Shewhart variation model consists of the following three components (Figure 9):

1. A centerline, usually equal to the mathematical average of all the samples plotted.
2. Upper and lower statistical control limits, which define the constraints of the variations.
3. Performance data plotted over time associated with quality patterns.

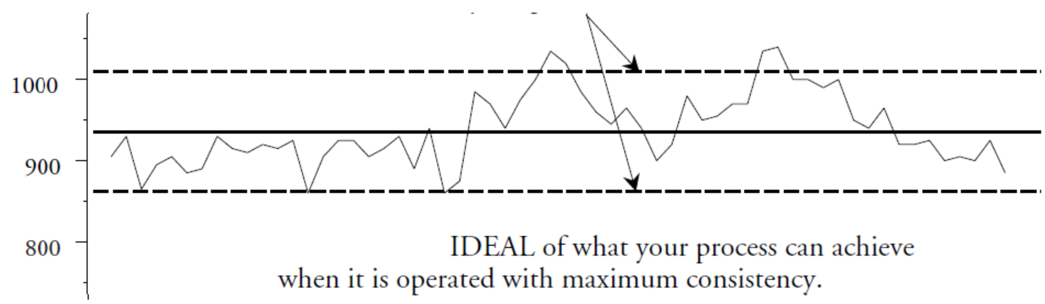


Figure 9. Shewhart's Variation Model within Consistency Barriers. Shewhart’s variation chart demonstrating that variation should always pivot around a standard or constant (center-line) and never be allowed to steer away from the standard or constant.

In modern production, variation control is of utmost importance based on the fact that non-corrected deviation patterns can cause high cost and low quality output. The contributions by these pioneer theorists greatly influenced production outcomes in the past as well as today. The inception of quality theory in production allowed organizations to create products of high quality at low cost (Juran, 1989). These quality pioneers and their respective contributions to quality control in manufacturing paved the way for Japanese lean theory development, which will be discussed in the next section.

Japanese Lean Theory

Through their tenacious quest to improve production quality, the Japanese have devised strategies for creating a revolution in production and quality improvement on a global scale. Their quality improvement efforts were largely based on quality theory contributions by Deming, Juran, and Shewhart. Over time, refinement upon refinement on production and quality improvements in manufacturing came to be known as Japanese lean theory, out of which grew the TPS framework (Figure 10).

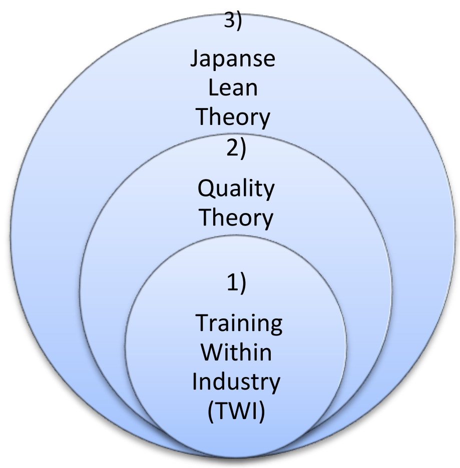


Figure 10. Inception of Japanese Lean Theory. Development of Japanese lean theory and its connection to TWI and quality theory.

Japanese lean theory, or as it is also known, the TPS framework, centers around the following four principles as borrowed from TWI and quality theory frameworks (Womack et al., 1990):

- Long Term Philosophy. Upper managers must personally take charge of leading quality improvement within their organizations.
- The right process will produce the right results. Quality control is undertaken on a continuous reevaluation cycle.
- Invest in people and partners. All levels and functions within organizations must undergo training in managing quality.

- Continuous problem solving. The workforce is enlisted in quality improvement through a quality control cycle concept.

The Toyota Motor Company developed a management philosophy unique to production and quality control in manufacturing, which came to be known as the TPS model. The TPS model has been described as a system designed to provide tools for workers to continually improve their work. The TPS model centers around management decisions: to think long term, to have a process for solving problems, to add value to the organization through the development of human capital, and to continually solve problems. The four principles as they constitute Japanese lean theory are accompanied by 14 subcategories, listed as follows (Liker, 2004):

- Principle One – Long Term Philosophy

Subcategory 1: Base all management decisions on long term philosophies, even at the expense of short term financial losses.

- Principle Two – The Right Process Will Produce the Right Results

Subcategory 2: Create process flow to expose problems and deviations to eliminate waste.

Subcategory 3: Employ a pull system to avoid overproduction. Such a system should produce needed materials on demand.

Subcategory 4: Level out the workflow through appropriate scheduling. A well defined schedule contributes to waste elimination and does not overburden people or equipment.

Subcategory 5: Create a culture capable of stopping and fixing problems as they surface to ensure maximized quality output.

Subcategory 6: Standardized processes and task development are the driving forces behind continued improvement and employee empowerment.

Subcategory 7: A standardized work environment contributes to high efficiency and the elimination of waste.

Subcategory 8: Utilize reliable and tested technologies that serve workers and add value to processes. Pull manufacturing versus push manufacturing is an applied method to reduce waste and increase customer value.

- Principle Three – Invest in People and Partners.

Subcategory 9: Grow leaders capable of leading who live the company philosophy and explain it to others. Leaders should guard against the failing of production principles.

Subcategory 10: Develop exceptional workers and teams that respect the company philosophy. Success is based on team accomplishments and not on individual efforts.

Subcategory 11: Value partners and suppliers by encouraging them to contribute to the company philosophy.

- Principle Four – Continuous Problem Solving

Subcategory 12: Managers are expected to align themselves with problem solving efforts in order to develop a thorough understanding of continued quality improvement.

Subcategory 13: Base decisions on slow consensus, through considering and evaluating all options. Upon reaching consensus, implement the decision immediately.

Subcategory 14: Become a learning organization through constant reflection and continued improvement.

The Toyota Motor Company successfully enhanced production and quality control processes in due course and adopted quality theory as part of their operating philosophy. In doing so they united production, quality, and management philosophies into a successful design model known as TPS. Based on the success of the TPS framework, adopting the framework became a desirable accomplishment among manufacturing operations across the world. Like many manufacturing industries, construction amended the TPS framework to its own operating platform (Koskela, 1992). The researcher evaluated how well lean research in the construction industry reflects the TPS framework. This is important based on the fact that research initiatives govern the implementation of theories within any given sector or industry (Lynham, 2002).

Lean Construction

Lean in construction can be viewed as an amended replica or desired replica of the TPS framework used in manufacturing (Koskela, 1999). Construction differs from manufacturing based on its physical features and the outcome of the end product. For example, in manufacturing, finished goods generally can be moved in whole to be stored by retailers or end consumers (Koskela, 1992). In contrast, construction deals with larger units that cannot be transported as freely or stored by retailers or end consumers. Based on this, construction is viewed to be fundamentally different in nature when compared to manufacturing.

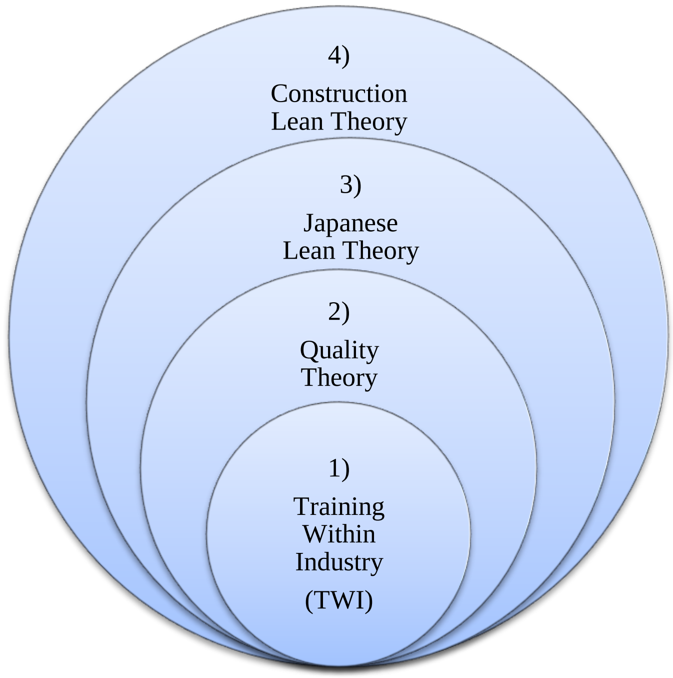


Figure 11. Construction lean theory and its connection to TWI, Quality, and Japanese Lean Theory.

In order to better understand the dynamics associated with the amenability of the TPS framework to the construction operating platform, it is imperative to be acquainted with the differences between manufacturing and construction operating platforms, which are site production, project uniqueness, complexity, and uncertainty, as discussed in Chapter One.

Succinct alignment of the TPS framework to the construction operating platform is an ongoing challenge in the construction industry based on the fact that construction operates on a different operating platform than that of manufacturing (Koskela, 1999).

Importance of Lean Construction Research

Lean construction theorists find it challenging to accurately bridge TPS theory principles to the construction operating platform (Green, 1999). The challenge stems in part from the fact that the TPS framework evolved over a long period of time within the manufacturing realm. According to Green (1999), confusion and disagreement about what comprises lean construction theory and how it can be measured operationally exists in the construction industry today, thus creating difficulty in lean's application to the construction platform.

According to IGLC, an array of lean construction theories exist, of which the following three are representative (IGLC portal, 2010):

1. Lean production is an integrated socio-technical system with the main objective of eliminating waste by concurrently reducing or minimizing supplier, customer, and internal variability.
2. Lean production is a manufacturing system with the objective of streamlining the flow of production while continually seeking to reduce resources, direct and indirect labor, equipment, materials, and space to produce a given set of items. Slack in the system is referred to as "waste."
3. Lean construction is a new way to manage construction. The objective, principles, and techniques of lean construction taken together form the basis for a new project delivery process. Unlike current approaches to managing construction and programmatic improvement efforts, lean construction provides the foundation for an operation-based project delivery system.

The Purpose of Theory

There is debate in the construction industry concerning the need for and applicability of lean theory in construction. Those in favor point to the success of similar theories in other industries, such as the automotive industry, as demonstrated by the Toyota Motor Company (Koskela, 2004). Theories play an important role in advancing professionalism and maturity in a discipline as well as to help ease tension between research and practice (Lynham, 2002). Torraco (2002) created the following in support of theory formulation, asserting that theories provide:

1. "A means by which new research data can be interpreted and coded for future use."
2. "A means for responding to new problems that have no previously indentified solutions strategy."
3. "A means for identifying and defining applied problems."
4. "A means for prescribing or evaluating solutions to applied problems."
5. "A way of telling us that certain facts among the accumulated knowledge are important and others are not."
6. "A means of giving old data new interpretations and new meaning."
7. "A means by which to identify important new issues and prescribe the most critical research questions that need to be answered to maximize understanding of the issue."
8. "A means of providing members of a professional discipline with a common language and a frame of reference for defining boundaries of their profession."

9. "A means to guide and inform research so that it can, in turn, guide development efforts and improve professional practice" (pp.117-119).

According to Whetten (1989) a well defined theory in research must answer the following four questions:

1. *What?* What factors, variables, constructs, and concepts logically should be considered as part of the explanation of the phenomena of interest?
2. *How?* How are these factors introducing causality?
3. *Why?* What is the rationale that justifies the selection of factors and the proposed causal relationship?
4. *Who*? *Where? When?* The boundaries of generalization and range of the theory have to be set.

Torraco (2000) further implies that theorists tend to pursue their work in ways that reflect their deep seated values and assumptions about what constitutes knowledge (epistemology), the nature of being or existence (ontology), what constitutes value (axiology), and other basic ideological and philosophical beliefs. According to Alvesson and Deetz (2000), what we are doing is developing informed knowledge frameworks about how to act on things in our world, thereby formulating ways in which to understand and address issues and problems in the world around us. Lynham (2002) wrote that, "Applied theory-building therefore requires researchers to interact with and be influenced and informed by their experience of the phenomenon in practice and their acquired knowledge/mastery of the phenomenon itself" (p. 228).

History of Lean Construction Research

The development of lean construction research started gaining ground in 1993 with the formation of the International Group of Lean Construction (IGLC). According to da CL Alves & Tsao (2007), the IGLC conference series was often a venue of choice for lean construction researchers as well as for practitioners to display their work and discuss different facets of lean construction research and implementation. The vision of IGLC is stated as follows: “To better meet customer demands and dramatically improve the Architect, Engineering and Construction (AEC) process as well as product” (IGLC Portal, 2010). The vision speaks to the pervasive need for lean research in construction related industries. Figure 12 illustrates the spike in lean construction research contributions by researchers on a global scale between 1993 and 2009. IGLC focuses its attempts on lean construction research and contributions by researchers across the world. IGLC further believes that the lack of lean research in construction has been a major bottleneck for the adoption of lean initiatives in the industry.

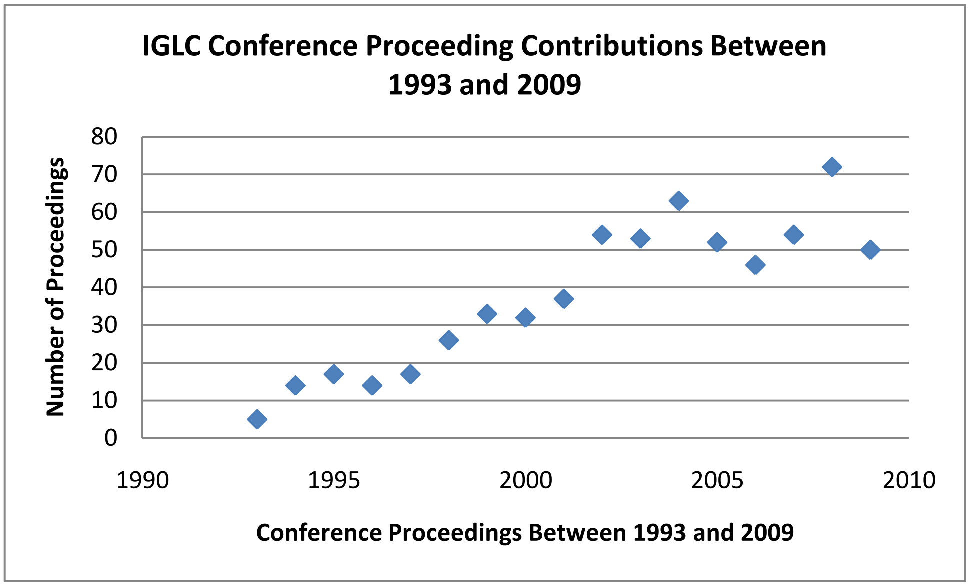


Figure 12. Rate of Construction Lean Research 1993-2009. Demonstrates the spike in research interests and contributions at IGLC annual conferences between 1993 and 2009.

Theory building introduces interplay between theory, research, and practice as illustrated in Figure 13 (Lynham, 2002). Research requires two kinds of expertise as it pertains to the field of inquiry: knowledge and experience. Lean in construction builds from the TPS framework as stated by Womack et al. (1990). Therefore lean construction can be viewed as an applied discipline stemming from lean theory.

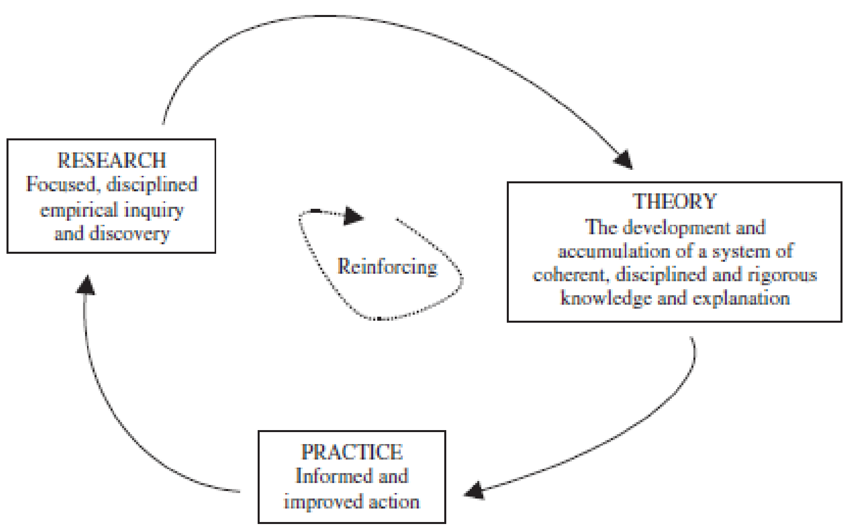


Figure 13. Applied Research Cycle (Lynham, 2002).

The interplay between theory, research, and practice forms the foundation of a five-step theory development model (Lynham, 2002). The interactive parts of this process include Conceptual Development, Operationalization, Application, Confirmation and Disconfirmation, and continuous refinement and development of the theory as illustrated in Figure 14.

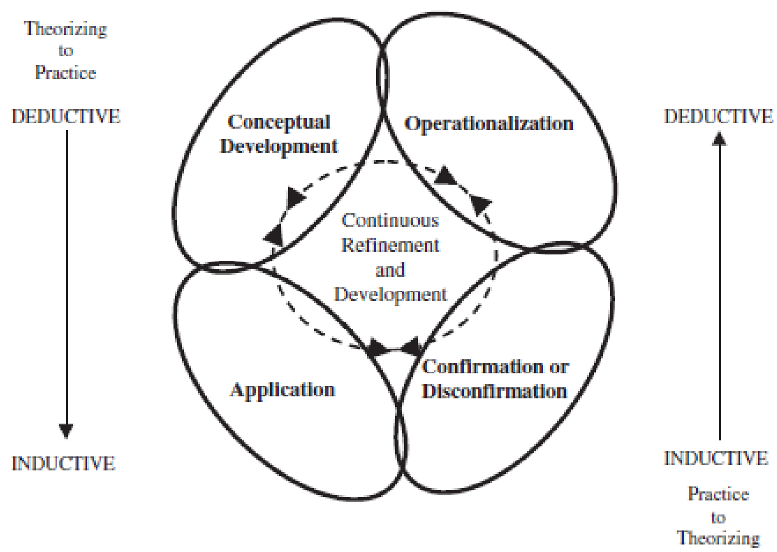


Figure 14. Research and Theory Development Model (Lynham, 2002).

These interactive parts are constantly refined based on the understanding that theory development and research is an ongoing phenomenon and never considered complete. Conceptual development requires that the researcher formulate initial ideas in a way that depicts current, best, most informed understanding and explanation of the phenomenon, issue, or problem in the relevant world context (Dubin, 1978). The purpose of this phase is therefore to develop an informed conceptual framework that provides an initial understanding and explanation of the nature and dynamics of the issue, problem, and/or phenomenon that is the focus of the theory (Lynham, 2002).

The Operationalization phase of research and theory-building is an essential connection between the conceptualization phase and practice (Lynham, 2002). It is during this phase that research gets tested in a real world context.

The Confirmation and Disconfirmation phase falls within the practice component of applied theory building (Lynham, 2002). This theory-building phase involves the planning, design, implementation, and evaluation of the appropriate research agenda and studies to purposefully inform and intentionally confirm or disconfirm the theoretical framework central to the theory (Lynham, 2002).

During the Application phase, further study, understanding, and inquiry of the research is ongoing. Based on the need for a more prominent lean theory framework in construction the researcher will focus on determining what current research contributes to the comparison between TPS and lean in construction.

Lean Theory Framework in Construction

The Machine that Changed the World (Womack et al., 1990), introduced a foundation framework of lean theory in construction. According to the authors, lean theory in construction consists of an array of complex concepts including: (a) continuous improvement, (b) flattened organizational structures, (c) teamwork, (d) elimination of waste, (e) efficient use of resources, and (f) corporate supply chain management.

These concepts outline the theoretical underpinning of lean construction as emulated from the TPS framework. Figure 15 illustrates a comparison between the TPS and construction lean frameworks and reveals that the TPS framework is a more extensive framework than the construction lean framework introduced by Womack et al. (1990). This comparison demonstrates a lack of equality between the TPS and construction lean theory frameworks.

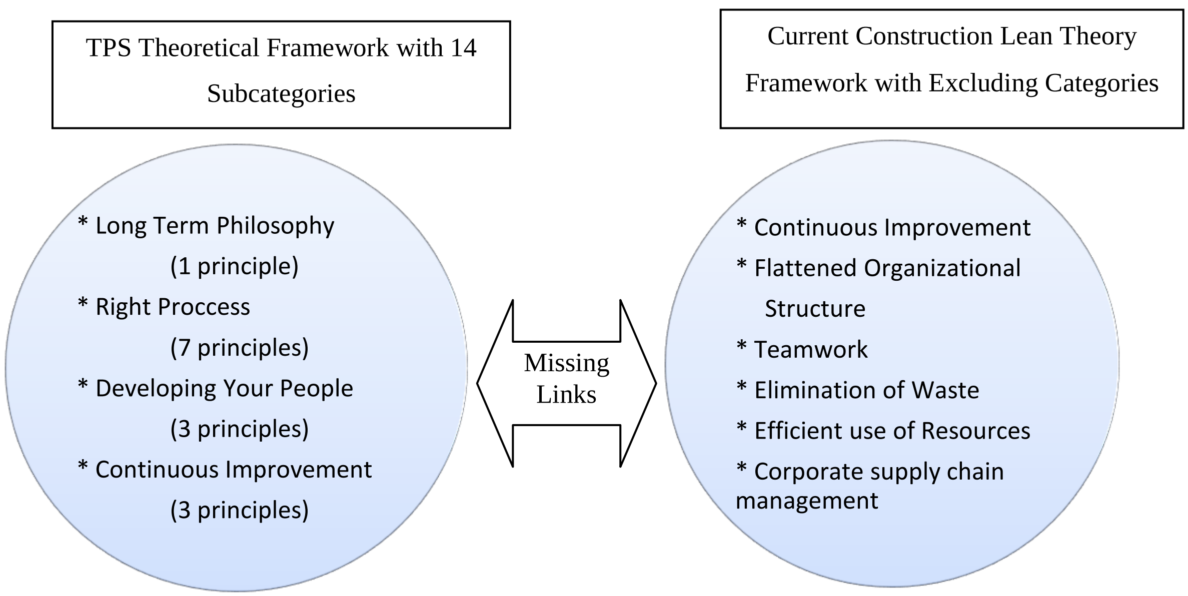


Figure 15. TPS and Construction Lean Theory Frameworks. A comparison between TPS and current construction lean theory frameworks.

According to Green (1999),

> The weak tie of lean research in construction is further based on the increasing influence of commercially vested interest over the publicly-funded research agenda which means a balanced portfolio of research is unlikely to occur (p.136).

The following problems further underscore lean construction research attempts (Shah & Ward, 2007):

1. Problems in lean construction research arise because some concepts have undergone a change in status over time.

2. Problems in lean construction research occur when identical items are used to operationalize vastly different concepts.
3. Problems arise in the reverse case in which different items are used to operationalize the same constructs.

The Need for Conducting This Study

Despite the challenges facing the construction industry in constituting a lean theoretical framework unique to its own operating platform, the importance of such a framework should not be underestimated. Alignment of IGLC research studies to the TPS framework in construction will create greater awareness among construction researchers for a more balanced foundation of lean knowledge. According to Fellows and Liu (2003) a discipline or profession is established by developing a body of knowledge that is unique to its operating platform which is produced through research. The researcher in this study further states that construction research draws on a wide variety of established subjects, including natural sciences, social sciences, engineering, and management. Only by way of appropriate methodologies and methods of research, applied with rigor, can the body of lean knowledge for construction be established and advanced with confidence. The TPS framework is a proven production model in manufacturing that emerged from TWI, arising from World War II manufacturing needs. Extrapolating and applying knowledge from this proven production model will add to the foundation of lean knowledge in an industry concerned with creating the built environment.

CHAPTER THREE: RESEARCH DESIGN AND METHODOLOGY

Overview

The purpose of this chapter is to describe the methodology used in this study. The study aligns lean research literature from the International Group of Lean Construction (IGLC) database for comparison against the TPS framework in order to determine if lean research in construction is representative of the TPS framework as described in the book *The Toyota Way* (Liker, 2004). Content analysis was used to align IGLC research studies between 1996 and 2009 to the TPS framework. An ideal alignment of these studies against the framework would reveal that lean research in construction is representative of the TPS framework. A less ideal alignment would point out omitted TPS principles in construction lean research.

Methodology

Research can be classified as qualitative, quantitative or mixed in its design structure. Qualitative research focuses on attitudes, behaviors and experiences through interviews of groups, where quantitative research focuses on the generation of statistics through the use of survey research such as questionnaires or structured interviews. Mixed methods integrate quantitative and qualitative research. This study was classified as qualitative in nature and used content analysis as the chosen methodology for conducting this study. Content analysis utilizes a set of procedures to make valid inferences from texts to answer research questions. As will be explained, the analyses of IGLC research studies in this study strictly complied with the procedures associated with content analysis. An important attribute of content analysis is the generation of cultural indicators that point to the state of beliefs, values, ideologies, or other cultural systems (Weber, 1985). Content analysis is used in many research studies to: (a) reflect cultural patterns of groups, institutions, or societies; (b) describe trends in communication content; (c) reveal the focus of individual, group, institutional, or societal attention; (d) describe attitudinal and behavioral responses to communications; and (e) detect the existence of propaganda (Berelson, 1952). This study utilized content analysis to describe trends in communication content and reveal the focus of the group IGLC.

Compared with other data generating and analysis techniques, content analysis has three additional advantages:

- Content analysis yields unobtrusive measures in which neither the sender nor the receiver of the message is aware that it is being analyzed. Hence, there is little danger that the act of measurement itself will act as a force for change that confounds the data (Weber, 1985).
- Content analysis studies can utilize both qualitative and quantitative operations within literature. The researcher focused strictly on qualitative research studies, based on the theoretical underpinning of lean construction.
- If documents of various kinds exist over long periods of time, cultural indicators generated from such series constitute reliable data (Weber, 1985). The data utilized in this study spans a 14-year period, therefore providing reliability to the study.

Based on these advantages and how they relate to this study, content analysis provided a solid research foundation for this study.

Research Framework

The nature of content analysis is that large datasets can be classified into more relevant content categories. According to Weber (1983), researchers must judge what method is most appropriate for their study. Figure 16 represents the research framework within a four step process as it relates to this study. Each step was processed in its entirety before moving on to the next step. This process can be viewed as an empirical research endeavor, with an emphasis on deductive coding, seeking to establish if lean research in construction is representative of the TPS theoretical framework.

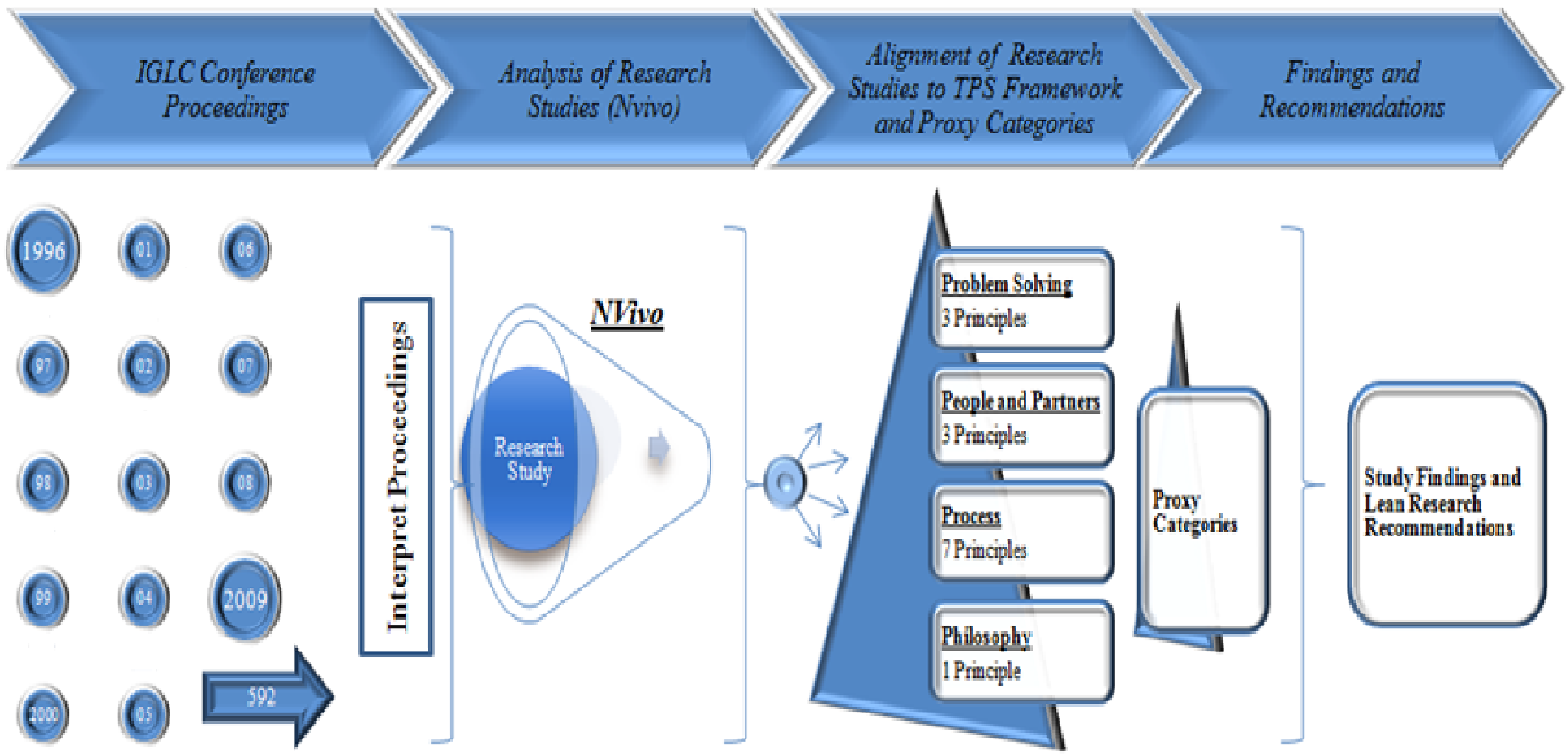


Figure 16. Research Framework: A representation of the various research steps associated with this study.

The research framework for this study consisted of four steps. First, a database was compiled for analysis that consisted of IGLC research studies between 1996 and 2009. Second, the IGLC database was uploaded into NVivo, a qualitative data analysis (QDA) software program. NVivo has been designed for qualitative research studies working with rich text-based and/or multimedia information, where deep levels of analysis on small, medium, or large volumes of data are required. Each literature piece was analyzed by looking for exploratory findings. According to Robson (2002) exploratory and confirmatory analysis are the two main extensions in qualitative inquiry. Exploratory analysis investigates the data which in this study centered around IGLC research studies. Third, the IGLC research studies were analyzed and aligned against the TPS framework. For the research studies to be classified within the TPS framework they had to conform to the TPS subcategory framework, which consists of a 14-point outline as introduced in Chapter Two. Research studies that did not conform to the TPS framework were further classified into one of 15 proxy categories as they emerged from the content analysis during the course of the study. This was important because the researcher found emerging and recurring research categories that were not addressed in the TPS framework. In cases where more than 5 studies occurred with a similar focus the researcher created and defined a proxy category. Breaking the non-TPS studies into further categories allowed for greater understanding of emerging lean research. Creating proxy categories allowed all research studies to be analyzed despite nonconformance or lack of relevance to the TPS framework. Finally, drawing on the findings in step three, recommendations were constructed to answer the research question, namely, is lean research in construction representative of the TPS framework?

Validate Content Analysis

The framework for the study was based on Krippendorff's (2004), six questions which must be addressed in every content analysis study:

1. Which data are analyzed?
2. How are they defined?
3. What is the population from which they are drawn?
4. Is the context related to the data analyzed?
5. What are the boundaries of the analysis?
6. What is the target of the interference?

The following summary answers the six questions in a manner suitable to create the study framework.

1. Which data are analyzed? In 1993 IGLC was founded to represent lean research initiatives in construction across the world (IGLC portal, 2010). IGLC research studies include but are not limited to work by academics, practitioners, and consultants covering a wide range of lean initiatives as they relate to lean research in construction. By analyzing IGLC research studies between 1996 and 2009, the study captured specific research trends in lean construction research. The first three years of IGLC research studies between 1993 and 1996 were not available for inclusion in this study.
2. How are they defined? IGLC is representative of lean research as it relates to architecture, engineering, and construction industries across the world. All research studies analyzed in this study were selected from the IGLC research database between 1996 and 2009.

3. What is the population from which they are drawn? The population consisted of all IGLC research studies between 1996 and 2009.
4. Is the context relative to the data analyzed? Indeed, IGLC is a group specifically dedicated to the furtherance of lean research in construction. Therefore their conferences are a valid venue for the discussion of lean research initiatives in the construction industry.
5. What are the boundaries of the analysis? The boundaries cover lean initiatives in construction over a 14-year period as compared against the TPS theoretical framework.
6. What is the target of the interference? The target of the interference determined if lean research themes in construction were representative of the TPS theoretical framework.

Six Step Research Sequence

With the framework established a research sequence was developed and Rodson's six steps were chosen. According to Robson (2002), content analysis studies are framed within the following six steps: (a) start with a research question, (b) decide on sampling strategy, (c) define recording units, (d) construct categories for analysis, (e) test the codes and samples for reliability and validity, and (f) carry out the analysis (Robson, 2002, pp. 352-357). These steps guided the course of this study as will be explained under each of the following sub-headings.

Start with a Research Question

The objective of this study was to compare IGLC research studies against the TPS framework. The intent of this study was to determine how well these categories were represented in IGLC research studies between 1996 and 2009. Addressing the alignment between lean construction research and the TPS framework, the research question was stipulated to direct the course of this study. Under the research question, seven sub-questions were formulated.

Research Question: Is lean research in construction representative of the TPS framework as put forth in *The Toyota Way* (Liker, 2004)?

- Sub-question one: What percentage of IGLC analyzed research studies are classified within the TPS framework?
- Sub-question two: Of the research studies classified within the TPS framework, what is the distribution of studies into each of the four subcategories?
- Sub-question three: Over the 14 years of IGLC conference research studies, what is the trend of contribution in each of the four TPS subcategories?
- Sub-question four: What lean related research categories within a percentage breakdown structure emerged from the IGLC conference research studies between 1996 and 2009?
- Sub-question five: What were the research trends between 1996 and 2009 within these lean related research categories?
- Sub-question six: What research methods were used in IGLC research studies between 1996 and 2009?
- Sub-question seven: What has been the level of contribution of different countries to IGLC research studies from 1996 to 2009?

Decide on a Sampling Strategy

The sampling strategy for this study centered on IGLC research studies based on the premise that these research studies are representative of lean research in construction as stipulated in the IGLC mission statement.

A total of 592 IGLC research studies were evaluated in this study. Table 5 lists the year, location, and number of IGLC conferences held over the last 14 years. Countries across the globe contributed to the body of construction lean research.

Table 5

Compilation of Year, Location, and Number of Literature Contributions of IGLC Proceedings Over the Last 14 Years

Conference Year	**Location of Conference**	**Number of Publications**
1996	Birmingham, USA	13
1997	Gold Coast, Australia	16
1998	Guaruja, Brazil	25
1999	Berkley, USA	33
2000	Brighton, USA	32
2001	Republic of Singapore	35
2002	Gramado, Brazil	54
2003	Blacksburg , USA	52
2004	Elsinore, USA	63
2005	Sydney , Australia	52
2006	Santiago, Chile	42
2007	Michigan, USA	53
2008	Manchester, UK	73
2009	Taipei, Taiwan	59
	Total	**592**

Define the Recording Units

Content analysis can utilize an entire population of documents or a partial sample depending on the view of the researcher. In content analysis three sampling populations exist (Robson, 2002): communication sources, document sampling, and texts within documents. This study focused on document sampling drawn from all the IGLC research studies between 1996 and 2009 as they relate to AEC industries.

Construct Categories for Analysis

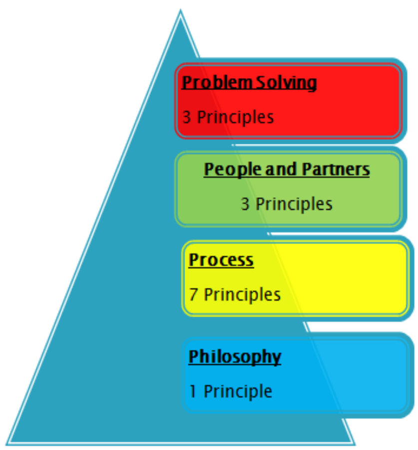
According to Weber (1985) researchers may obtain a perspective on text by examining the highest frequency of words, because each word accounts for a relatively large proportion of the text. Robson (2002) points out that different categories of analysis can be used in content analysis including: subject matter, direction, values, goals, methods, actors, and location. This study did not intend to analyze for high frequency words, but rather focused on subject matter for interpreted meaning of IGLC conference proceedings. Upon interpreting 592 IGLC research studies; the researcher classified each study within one of the four TPS categories or in one of 15 proxy categories.

Test the Codes and Samples for Reliability and Validity

Code Schemas. Content analysis often calls for the design and implementation of code schemas from the following list: word selection, word sense selection, sentence selection, theme selection, paragraph, or whole text selection. This study focused on whole text selection based on the interpretation of IGLC research studies and included the following two basic code schema measures.

1. The researcher had to determine if the four TPS categories were mutually exclusive. All TPS categories within the study were classified as mutually exclusive. A proceeding could only belong to a single category within the TPS framework or to one of the 15 proxy categories.
2. The researcher had to determine the range of categories. The category ranges in this study were classified as shown in Figure 17. For example if a research proceeding showed a relationship to long term thinking it was placed under Philosophy within the framework structure due to the fact that long term thinking is a principle of the TPS

category Philosophy. Similar examples were applied under Process with seven principles, People and Partners with three principles, and Problem Solving with three principles. A research study could belong to more than one of the 14 TPS principles under the primary category. For example a proceeding could belong to Create Process Flow as well as to Use Pull System, both classified under Process within the TPS framework. The theoretical framework model in Figure 17 defines the code schemas utilized in the study.



TPS Theoretical Framework Outline			
1	Long Term Thinking	8	Use Tested Technology
2	Create Process Flow	9	Grow Leaders
3	Use Pull System	10	Respect People
4	Level out Workload	11	Respect Suppliers
5	Stop for Quality Problems	12	Continuous Learning
6	Standardize Tasks	13	See and Understand the Situation
7	Use Vision Control	14	Make Decision Slowly, Implement Rapidly

Figure 17. TPS Theoretical Model.

Reliability. Three types of reliability are unique to content analyses: stability, reproducibility, and accuracy (Stemler, 2001). This study addressed two types of reliability—stability and reproducibility. Stability refers to the results of content classification, when the same content is coded more than once by the same coder in the same fashion (Stemler, 2001). Upon completion of the research study analysis the researcher randomly selected 5% of the analyzed proceedings (30 proceedings), which were then re-analyzed by the researcher in the same manner as before. A stability coefficient of 96% percent indicated a strong reliability factor within content classification (Krippendorff, 2004) as shown in Appendix A.

Reproducibility refers to the extent to which content classification produces the same results when the same text is coded by more than one coder. An external interrater evaluator was utilized to test 10% (60 proceedings) of previously analyzed proceedings by the researcher. This individual had no connection to the study and was purely contracted based on her construction and qualitative research background. Her credentials and interrater findings are listed in Appendix B. An interrater reliability factor of 92% indicated an acceptable reproducibility factor (Krippendorff, 2004) as shown in Appendix B.

Validity. Validity is a general term most often used by researchers to judge quality or merit (Morgan, Gliner, & Harmon, 2006). Validity relates to both design and methods within research. Validity indicates that findings truly represent the phenomenon being measured (Morgan et al., 2006). Validity is mostly concerned with the controlling of factors that might have an effect on the research outcome. Validity can be classified as either internal or external in nature. Although none of these factors played a role in this study due to the use of an existing database a short discussion of each type of validity is provided..

Internal validity is affected by mistakes within the study itself or with problems within the research instrument. Findings can be said to be internally invalid if they may have been affected by factors other than those thought to cause them, or if the data by the researcher was not clearly supportable (Seliger & Shohamy, 1989). There are numerous factors that can affect internal validity: subject variability, size of subject population, time given for data collection, history, attrition, maturity, and instrument.

External validity has to do with whether findings can be generalized to a larger group or another context. Findings can be said to be externally invalid if they cannot be extended or applied to contexts outside those in which the research took place (Seliger & Shohamy, 1989).

The following factors can affect external validity: population characteristics, interaction of subject selection and research, research environment, time, and data collection method (Seliger & Shohamy, 1989). This study focused on IGLC conference proceedings exclusively where interpretations were generalized to lean research in construction.

Trustworthiness relates to this study and causes it to be "worth paying attention to" (Lincoln & Guba, 1985, p. 290) because the data comes directly from researchers in the field. Each of the 592 research studies was blind reviewed by three industry experts prior to being accepted for presentation at the IGLC conferences, lending credence to their findings. This in turn allowed this researcher to analyze peer reviewed research in a content analysis context.

Carry out the Analysis

This study used content analysis to analyze IGLC research studies making recommendations on lean research themes in construction through a four step process. Due to the design of the study, each step had to be processed in its entirety before the study could move to the next step. This study utilized both exploratory and confirmatory analysis, as discussed earlier, in making recommendations as far as lean research initiatives. This study was viewed as an empirical research endeavor, with an emphasis on deductive coding, seeking to establish a claim for lean construction research themes as collected from IGLC research studies. This study further established a comparison between IGLC research studies and the TPS framework as a way to evaluate lean research initiatives in construction.

Analysis Sequence

An explanation of the analysis utilized in the study follows. NVivo is a qualitative data analysis (QDA) software program designed for working with rich text-based and/or multimedia information where deep levels of analysis on small, medium, or large volumes of data are required. The scale on which this study took place required the utilization of a qualitative data analysis software program like NVivo for organizational as well as quality purposes. The following six indicators, labeled A through G, in Figures 18 through 21 illustrate the NVivo analysis sequence utilized in this study.

1) All IGLC research studies contributed between 1996 and 2009 were converted from .pdf format to Microsoft .doc format. All 592 research studies grouped by year of inclusion in the proceedings were uploaded into NVivo as indicated by A in Figure 18.

2) Upon uploading of these documents, all research studies could be viewed electronically as illustrated by B, in Figure 18.

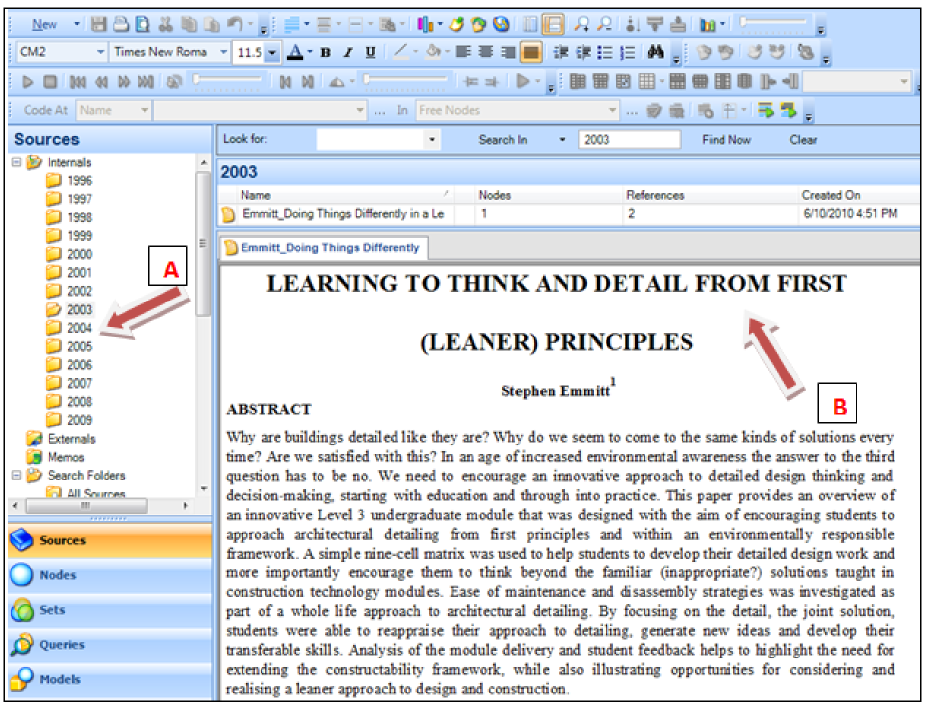


Figure 18. NVivo Interface Example 1.

3) Each research study was either classified into one of the four TPS categories, or one of 15 proxy research categories according to its research intent. Fifteen proxy research categories emerged during the course of the study. One of the 15 categories was

classified as "Outside Lean Framework" for research studies that could not be classified within the TPS or proxy categories based on its research intent. An NVivo function "Tree Nodes" indicated by C in Figure 19 allowed the researcher to group together research studies with the same research focus. Research studies were then classified within a specific research category as indicated by D in Figure 19.

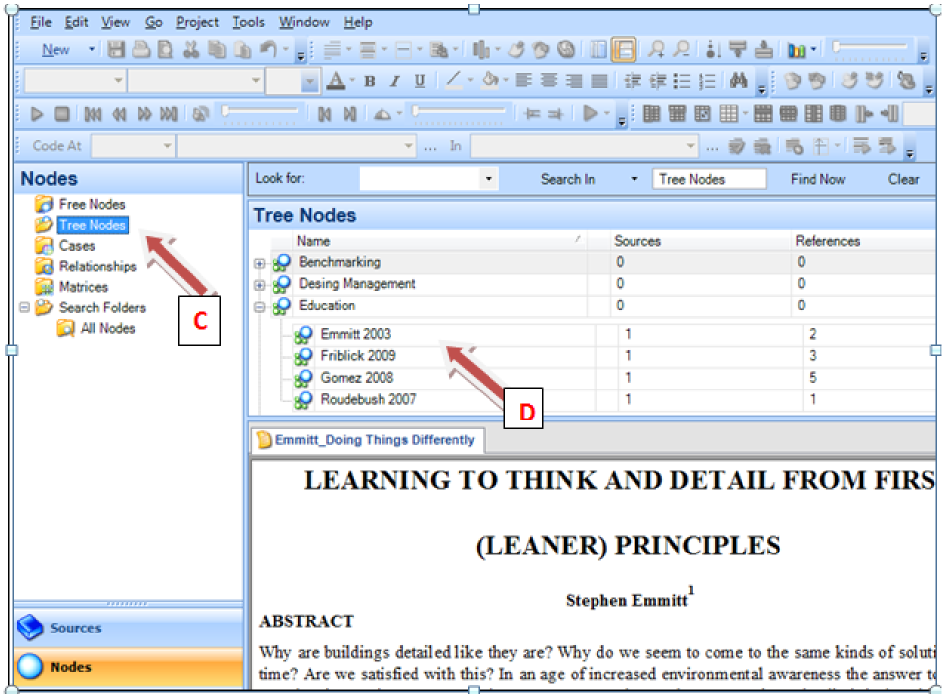


Figure 19. NVivo Interface Example 2.

4) Once an article was classified within a research category, NVivo created an automatic electronic reference list in support of its classification criteria. The reference number "2" indicates that two references were created for the Emmit research paper as illustrated in E in Figure 20. An example of an electronic reference list is displayed below E in Figure 20.

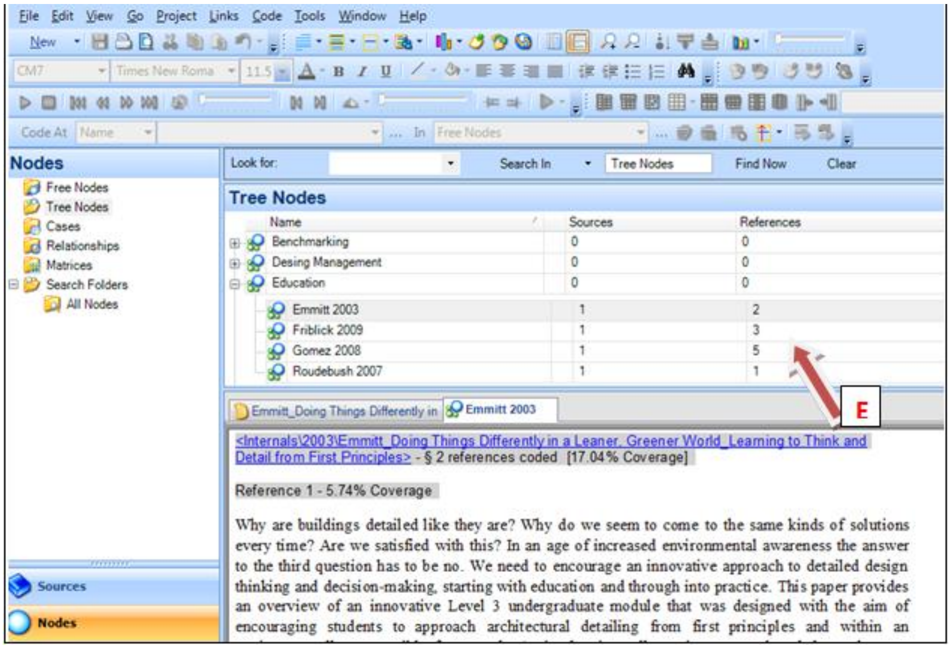


Figure 20. NVivo Interface Example 3.

5) In tandem with NVivo, a separate Microsoft Excel spreadsheet was created as indicated in F in Figure 21. The reason for this duplication was twofold. It served as a backup as well as allowed the researcher to extrapolate data for graph creation, which is a limitation of NVivo.

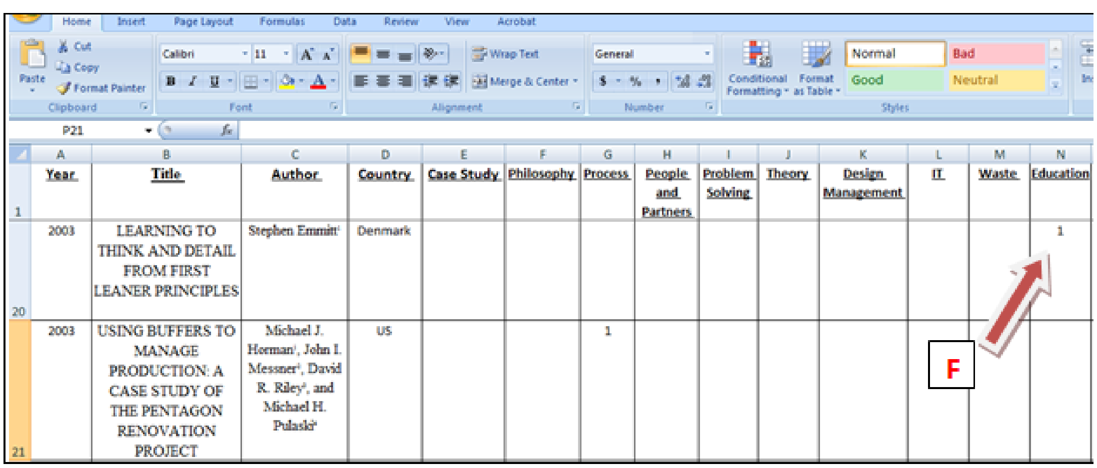
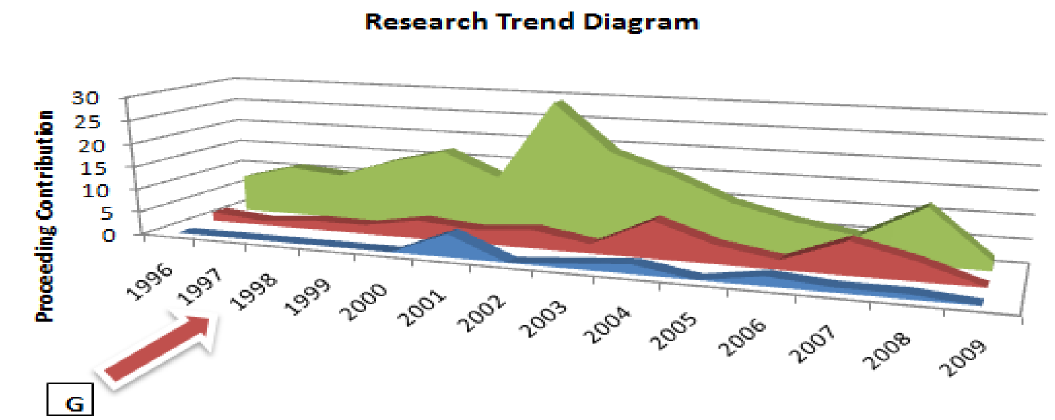


Figure 21. Excel Interface Example.

6) Upon the analysis and classification of the 592 research studies, interpretative representations in graph format accompanied the findings section as illustrated in G in the example graph in Figure 22.



	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Philosophy	0	0	0	0	0	5	0	1	2	0	2	1	1	0
People and Partners	2	1	2	2	4	3	4	2	8	4	2	7	4	0
Process	8	11	10	14	17	12	29	19	15	10	7	5	12	2

Figure 22. Examples of possible graph format.

Limitations in Content Analysis

This study utilized content analysis to analyze IGLC research studies for comparison against the TPS framework. It is known that data reduction in content analysis is associated with some limitations. In content analysis, reliability challenges usually stem from word meanings or the ambiguity of category definitions or similar coding rules (Weber, 1985). Guarding against these limitations the researcher implemented the following preventative measure:

- The researcher evaluated the merit of each IGLC research study in order to place it within one of the four TPS framework categories. Assignment of the research studies to categories largely depended on the research intent of each study. This study utilized interrater as well as intrarater reliability as the means to mitigate the ambiguity of reliability, category definition, and coding rules.

Classification by multiple human coders (interrater reliability) permits the qualitative assessment of achieved reliability against data reduction in content analysis (Weber 1985). Alternately, intrarater reliability refers to classification of the data by the same coder more than once expecting the same classification results. The study further embarked on a six step research sequence to ensure a sound outcome of results as will be discussed in the following section.

Contribution of This Study to the Field

The TPS framework can be applied to any industry, even though industries function on different operating platforms (Womack et al., 1990). The purpose of this study was to foster awareness of lean research among lean researchers in construction.

CHAPTER FOUR: RESEARCH FINDINGS

Chapter Overview

The objective of this study was to align construction lean research studies against the TPS framework, the application of which is responsible for impressive production outcomes in manufacturing around the world. This chapter provides an in-depth analysis on the research results of the study by way of addressing the primary research question, and its seven sub-questions.

Lean manufacturing has a certain maturity, in that there is considerable evidence of debate and application of lean theory among researchers and practitioners within manufacturing circles. In construction, a lean research debate seems to have developed more slowly (Womack et al., 1990). According to Green (1999) the lack of construction research as represented in peer-reviewed journals is a weakness facing the industry. Confronting and learning from this weakness should help rather than hinder the future development of a lean construction research platform. Critical discussion on the preconditions for, and limits of, a lean research platform in construction would greatly contribute to a stronger body of lean knowledge in the built environment.

Five hundred and ninety-two IGLC research studies were analyzed and classified within TPS and non-TPS categories (Figure 23). Sixty percent of these studies fell outside the TPS framework; 40% fell within. From the 40% of TPS classified studies, 71% were related to the

TPS category of Process, 19% were related to People and Partners, and 5% represented the categories of Problem Solving and Philosophy respectively.

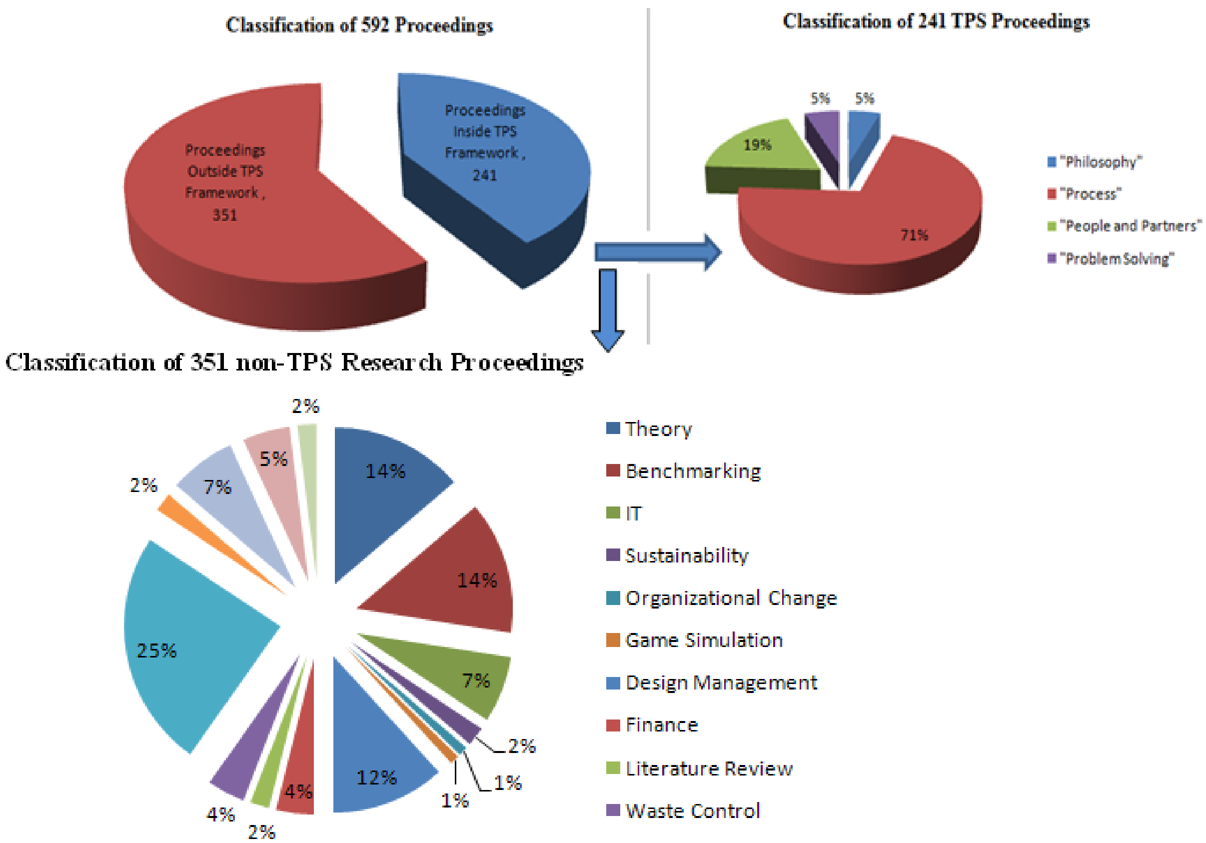


Figure 23. Illustration of IGLC proceeding breakdown. The TPS proceedings were grouped into one of the four TPS overarching research categories or in one of 15 proxy categories.

This chapter illustrates that past research in construction did not conform to the TPS framework principles as will be discussed following. From 592 IGLC research studies, 241(40%) were classified within the TPS framework and 351 (60%) were classified outside the TPS framework as fitting in one of 15 proxy lean related research categories. Table 6 is representative of the four TPS categories and the 15 proxy categories that were used to classify research studies according to their research intent. The listing on the left hand side of the table is representative of the four TPS categories namely: Philosophy, Process, People and Partners and

Problem Solving. The listing in the middle represents the 15 proxy categories with their respective definitions which guided the researcher in classifying research studies which did not conform to the TPS framework. A brief tabulation of definitions on these categories is illustrated in Table 6 to follow.

Table 6

Clarification of Research Categories

TPS Research Categories	Definition	Proxy Research Categories	Definition
Philosophy	Lean Theoretical Framework Category	**Theory**	Theory development research associated with lean construction
Process	Lean Theoretical Framework Category	**Benchmarking**	Compared construction processes and performances against that of other industries
People and Partners	Lean Theoretical Framework Category	**Information Technology**	Use of computers and telecommunication in construction
Problem Solving	Lean Theoretical Framework Category	**Sustainability**	Architectural property that allows continued viability in construction
		Organizational Change	Internal transformations within companies
		Game Simulation	Various activities in "real life" in the form of games
		Design Management	Integration of construction design into management and vice versa
		Finance	Construction activities associated with providing funds and capital
		Literature Review	Body of lean texts to review critical points of lean and construction

TPS Research Categories	Definition	Proxy Research Categories	Definition
		Waste Control	Measures of waste in construction
		Outside Lean Focus	No relevance to the four TPS categories or the 14 proxy categories in lean construction
		Prefabrication	Manufacturing of sections of a building at a factory
		Models and Feedback	Lean production models and feedback on applications in construction
		Safety	Safety systems in construction
		Logistics	Handling of operations in construction

Research Question

The research question inquired: Are research themes in lean construction representative of the TPS theoretical framework as put forth in *The Toyota Way* (Liker, 2004)? Taiichi Ohno, a prominent Japanese businessman, who is considered the pioneer of the Toyota Production System, stated the importance of the TPS framework as follows:

> The key to the Toyota Way and what makes Toyota stand out is not any of the individual elements…. But what is important is having all the elements together as a system. It must be practiced every day in a very consistent manner—not in spurts. (Liker, 2004, p. xv)

The TPS framework also influenced sectors outside manufacturing, for example, construction and service sectors (Liker & Meier, 2007). Toyota had success with the TPS model, and based on their success other manufacturers implemented the model as well.

The TPS framework consists of 14 principles clustered into four categories. The existing research studies were clustered according to their research intent within one of the four TPS categories or in one of the remaining 15 proxy categories which are lean related but are not listed within the TPS framework. Figure 24 represents the TPS framework and 14 principles used as the primary support in classifying IGLC research studies within the TPS framework.

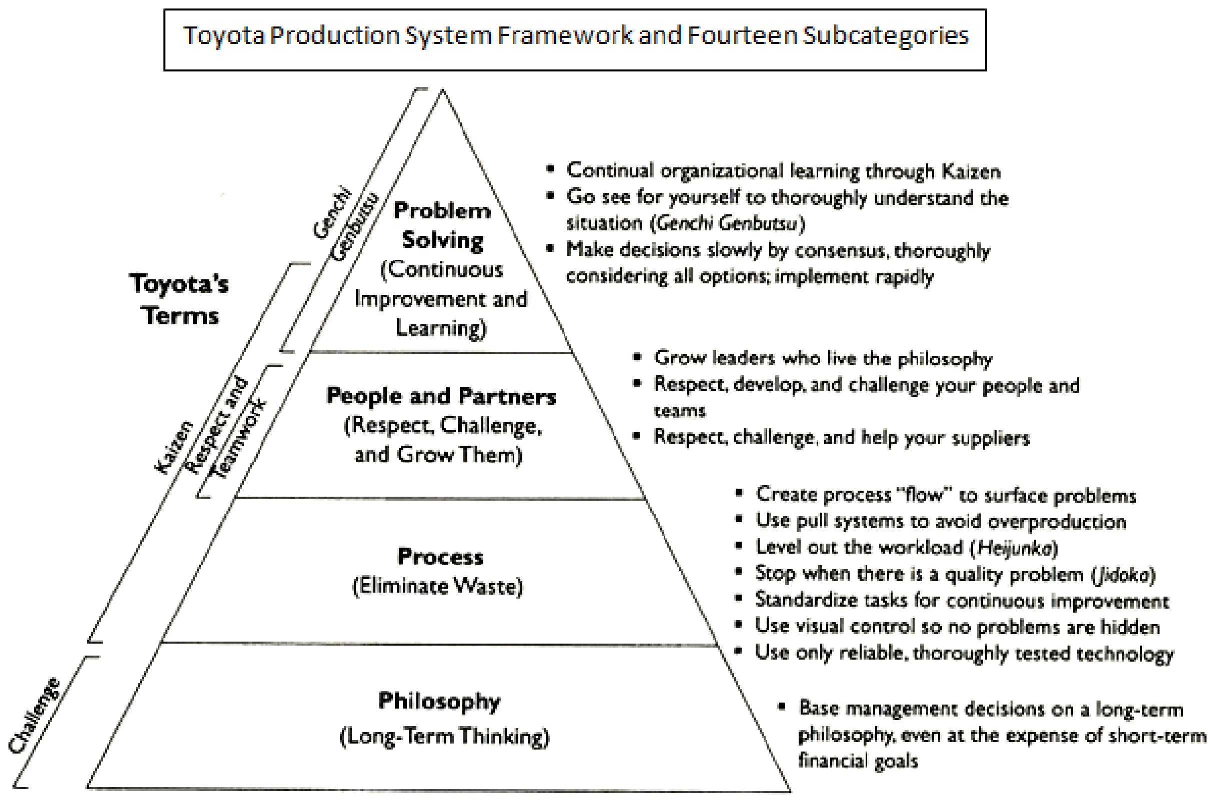


Figure 24. An illustration of the TPS framework consisting of four main categories and the corresponding 14 principles (Liker, 2004, p. 6).

The detailed summarization on the four overarching categories of this framework was introduced in Chapter Two, which provided an overview on each category and why these categories are deemed worthy by Toyota (Liker, 2004, p. xvi).

Analysis of Conference Proceeding Classification

The following seven sub questions support the overarching research question, as will be discussed below.

- Sub-question one: What percentage of IGLC analyzed research studies are classified within the TPS framework?

Figure 25 represents the breakdown of 592 IGLC research studies into TPS or proxy categories. It was evident from this breakdown that lean research in construction did not mirror the TPS outline. A total of 592 research studies were classified with 241(40%) within the TPS framework, and 351(60%) within one of 15 proxy categories. The studies were classified based on their research intent, relevance, and association to the 14 principles within the TPS framework.

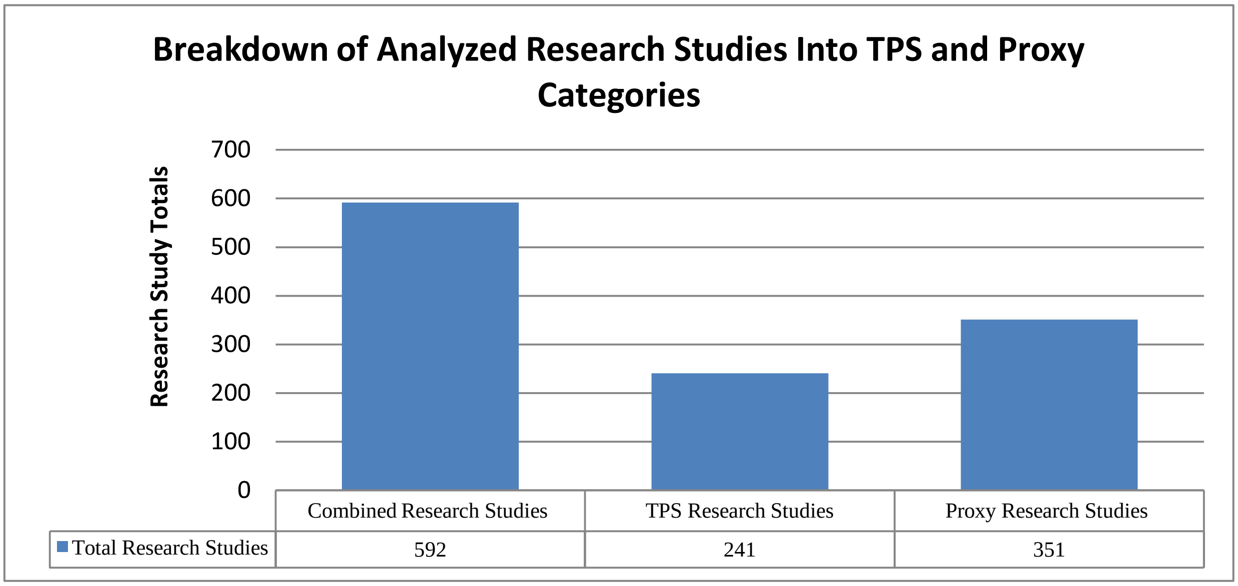


Figure 25. A breakdown of IGLC research studies into TPS or proxy research categories. A total of 592 proceedings were analyzed and grouped into 241 (40%) TPS and 351 (60%) proxy categories.

- Sub-question two: Of the research studies classified within the TPS framework, what is the distribution of studies into each of the four TPS subcategories?

The 241 studies that reflected the TPS framework were grouped, further unveiling an unequal representation of lean research interest among the four overarching TPS categories (Figure 26). Process was the most frequently referenced category.

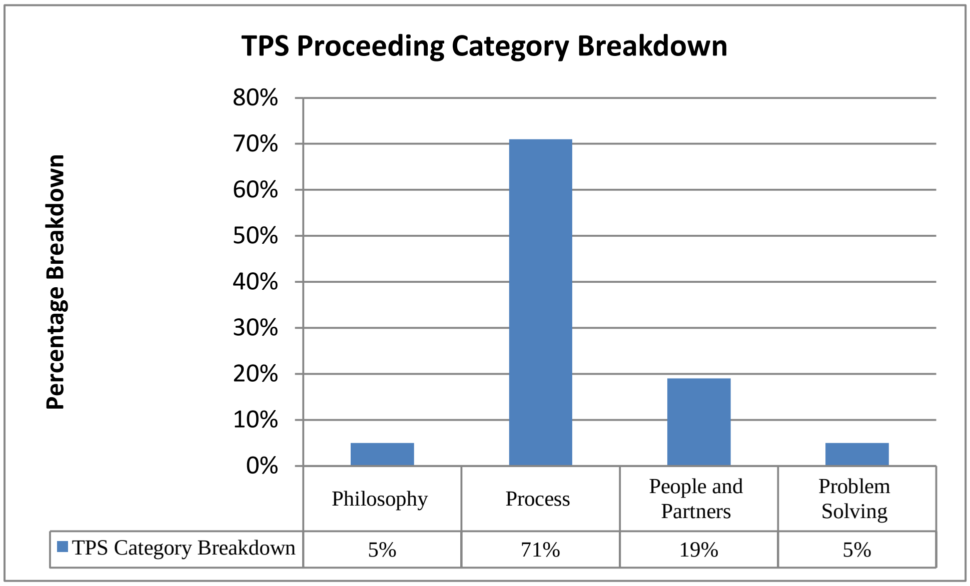


Figure 26. A breakdown of the 241 (40%) TPS research studies classified within the TPS framework.

This breakdown is representative of the 40% of findings classified within the TPS framework. Philosophy and Problem Solving each had 5% research representation, while Process had 71% research representation. People and Partners was represented by 19% of the studies. The studies that were not classified as TPS will be discussed under sub-question five.

The results of the breakdown shown in Figure 26, Philosophy, Process, People & Partners, and Problem Solving, are addressed in sub-question three and discussed individually below.

- Sub-question three: Over the 14 years of IGLC conference research studies, what is the trend of contribution in each of the four TPS categories?

Philosophy Research in Construction

The TPS principle of Philosophy is the underpinning and long term vision for a company. It is the foundation for the constancy of purpose which allows a business to steer toward a common goal. Toyota's business decisions are driven by its philosophies (Liker, 2004). John

Shook, a managing director at Toyota explains the importance of such a philosophy in the following way:

> Toyota initiated many years ago that it must focus on survival and the integration of all corporate functions toward ensuring its survival. Philosophy is the result of efforts to direct all activities to support the goal of a firm's survival (Shook, 2002).

The TPS Philosophy category consists of one TPS principle broken down into the following two parts

- Base management decisions on long term philosophies
- Do not allow short term financial goals to override long term vision

The findings of this study indicated a lack of lean construction research interest in Philosophy over the last 14 years. This lack of Philosophy research representation at IGLC conferences is visible in Figure 27 where red indicates the number of Philosophy research studies as compared to all studies at IGLC conferences between 1996 and 2009.

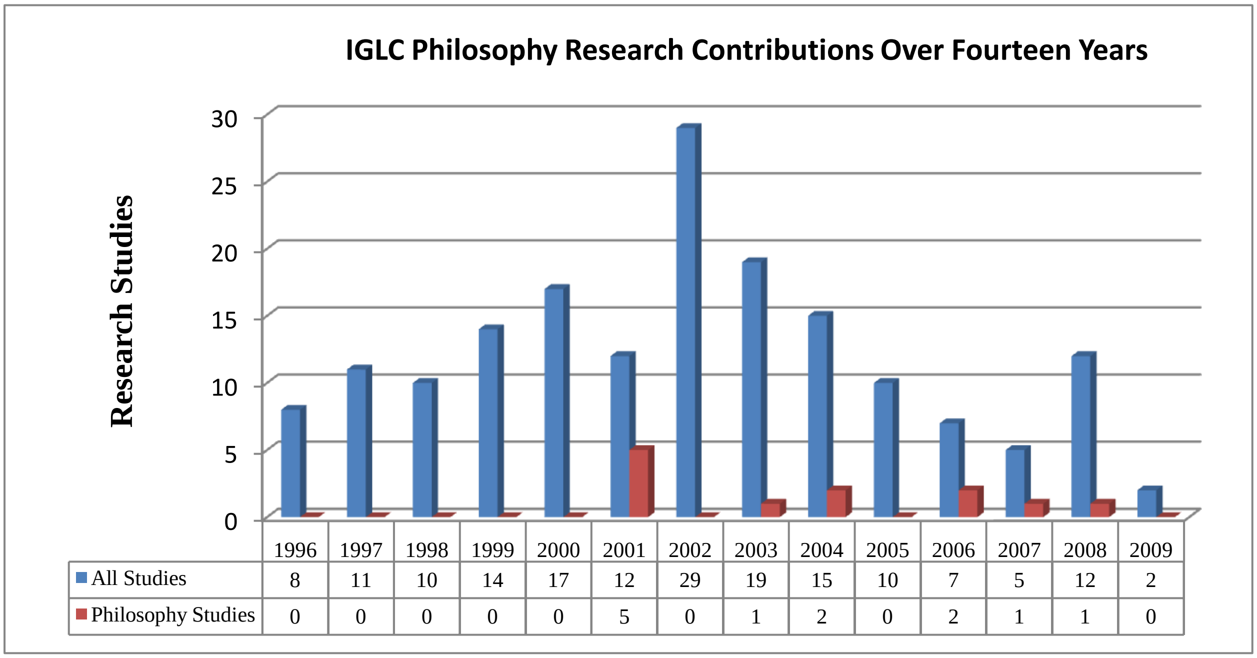


Figure 27. Breakdown of IGLC Philosophy research proceedings between 1996 and 2009.

Contributions of Philosophy research peaked in 2001 in comparison to years before and after. That year the IGLC annual conference was held in Santiago, Chile. The researcher investigated the percentage of Philosophy contributions by Chilean researchers during that year and confirmed the reason for the 2001 peak was due to local contributions by Chilean researchers. Philosophy research studies comprised 2% of all IGLC research studies over a 14 year period.

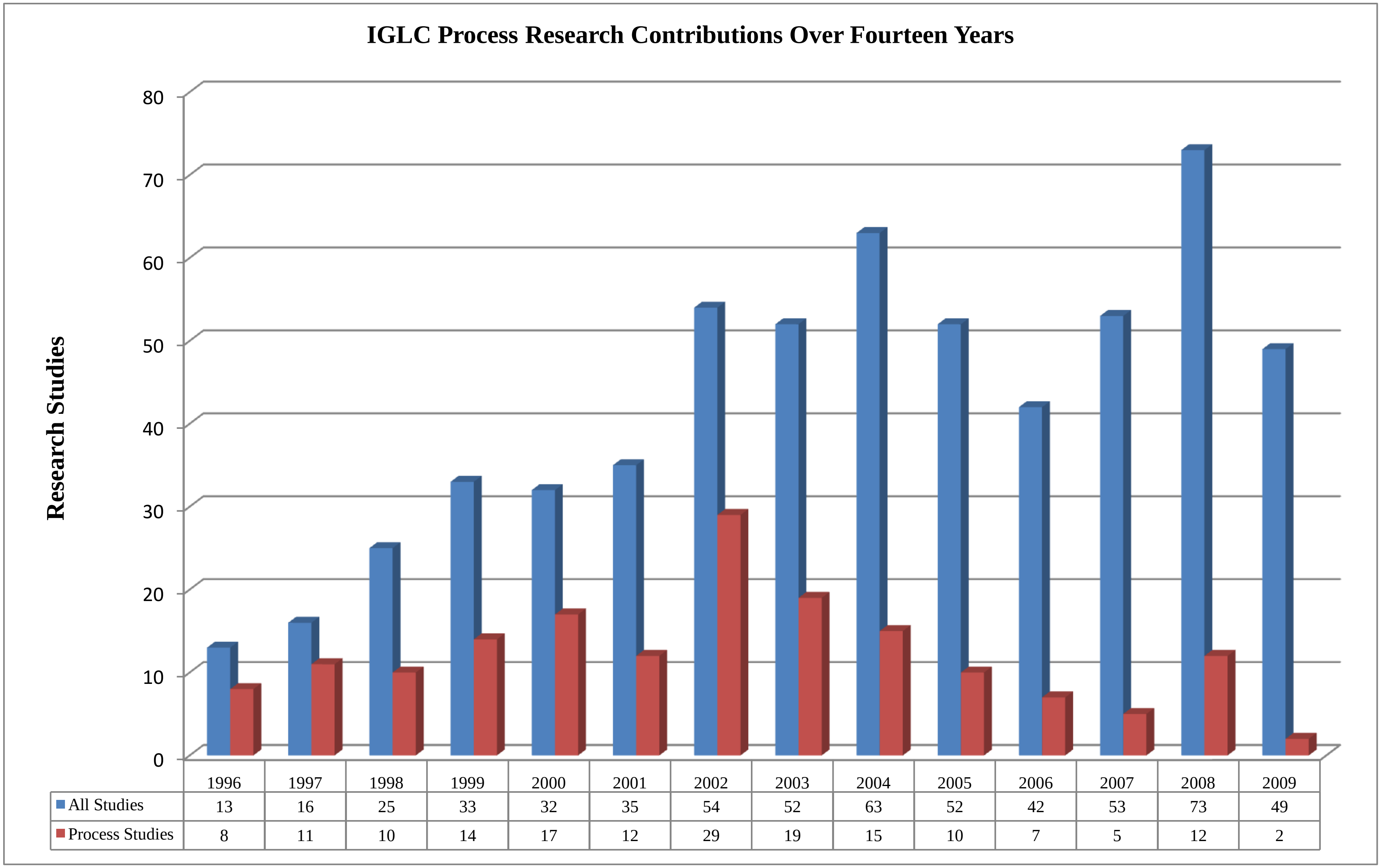
Process Research in Construction

Process within the TPS framework focuses on improving processes and process flows in organizations. According to Liker (2004) a good place for companies to begin their journey to lean is to create continuous process flow. The TPS Process category consists of the following seven principles.

- Create process “flow” to surface problems
- Use pull systems to avoid overproduction

- Level out the workload
- Stop when there is a quality problem
- Standardize tasks for continuous improvements
- Use visual controls so no problem are hidden
- Use only reliable, thoroughly tested technologies

IGLC Process research studies between 1996 and 2009 are illustrated in red as shown in Figure 28. The total contribution of research in this field is compared against all IGLC research contributions within a specific year. The peak of Process research study submissions was in 2002.



	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
All Studies	13	16	25	33	32	35	54	52	63	52	42	53	73	49
Process Studies	8	11	10	14	17	12	29	19	15	10	7	5	12	2

Figure 28. Breakdown of IGLC Process research studies between 1996 and 2009.

The TPS category Process supports day-to-day process flow activities in the field. Construction researchers have emphasized the importance of Process as a viable research area in construction as illustrated in Figure 28. This category contributed 28% of all IGLC conference proceedings between 1996 and 2009.

People and Partner Research in Construction

A cultural element for leaders at Toyota is to observe an actual production situation in detail. Leaders at Toyota must demonstrate this ability and understand how work gets done at the shop floor level (Liker, 2004). Toyota also expects its leaders to teach their subordinates the Toyota Way which means they must understand and live the company philosophy. Toyota does not go shopping for "successful" CEOs and presidents; they believe their leaders must live and thoroughly understand the Toyota daily operating culture. In contrast, leaders in Western companies are not in place for long enough to build a mature culture to match their personal vision (Liker, 2004). The underlying challenge with outside leaders who implement radical change in the culture of organizations is that an organization never learns but rather loses the ability to build on achievements, mistakes, or enduring principles. For this reason the TPS category People and Partners speaks to this issue through the following three category principles.

- Get leaders who live the philosophy
- Respect, develop, and challenge your people and teams
- Respect, challenge, and help your suppliers

Figure 29 is representative of IGLC research studies in the People and Partners category between 1996 and 2009. This category has low research representation, only 7.6%, despite the critical importance of the integrated dynamics of people in work teams, and as independent contractors, architects, engineers, and shareholders in construction.

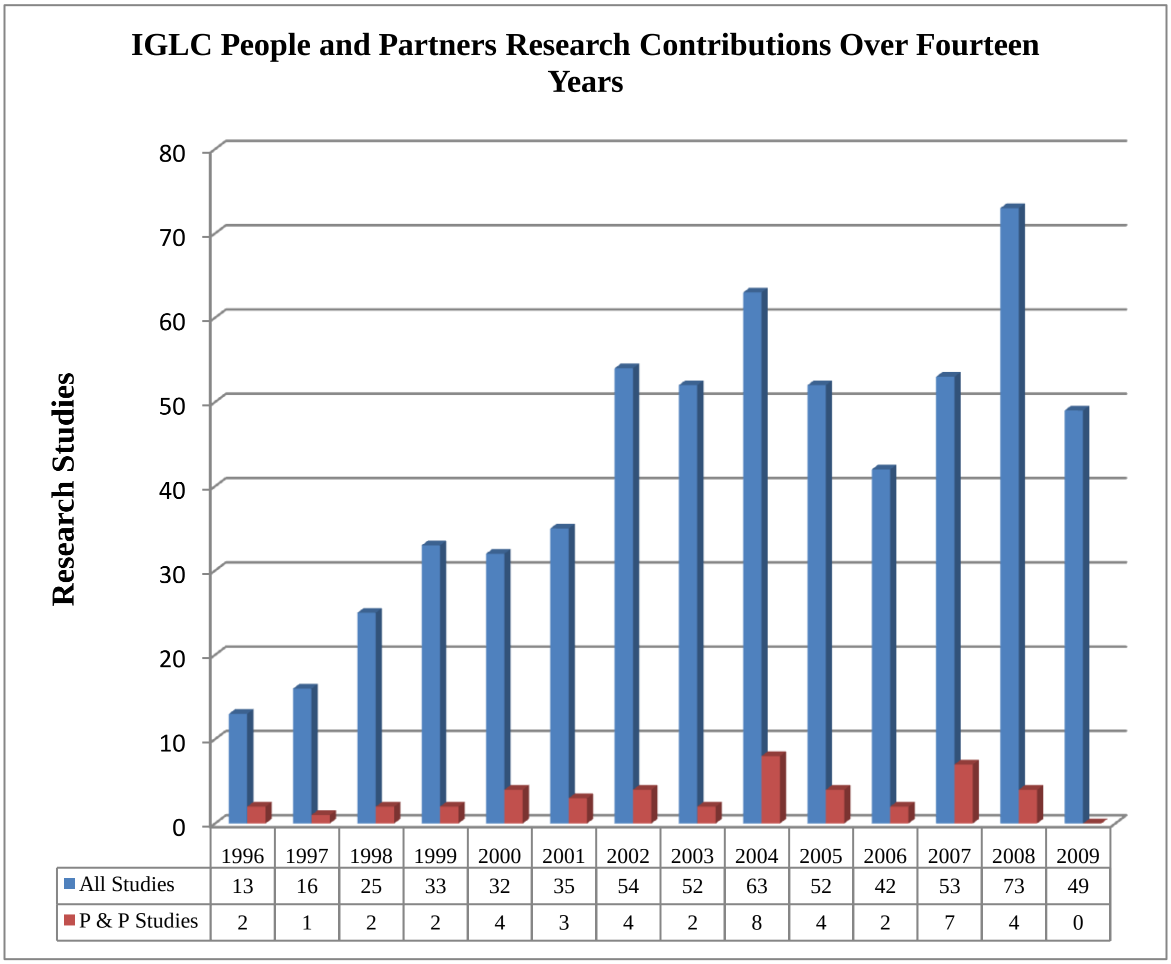


Figure 29. Breakdown of IGLC People and Partners research studies between 1996 and 2009.

Problem Solving Research in Construction

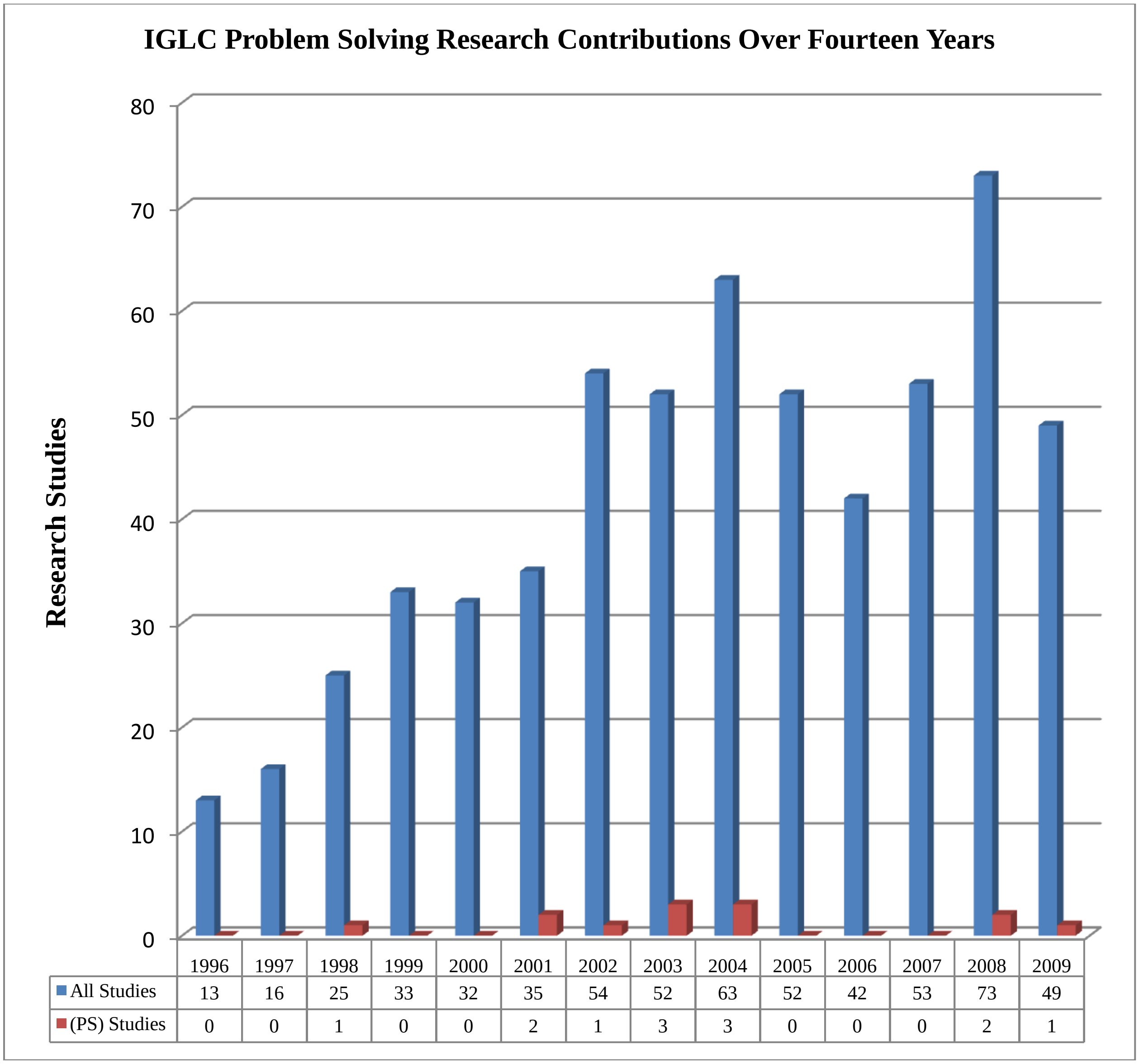
The Toyota Way requires that employees and managers understand the process of flow and standardized work as well as have the ability to critically evaluate and analyze what is going on during operations. Workers at Toyota must know how to get to the root cause of any problem they observe and communicate it effectively to others. As Tadashi Yamashina, president of the Toyota Technical Center explained:

> It is more than going and seeing. "What happened? What did you see? What are the issues? What are the problems?" Within the Toyota organization in North America, we are still just going and seeing. "OK, I went and saw it and now I have a feeling." But have you really analyzed it? Do you really understand what the issues are? At the root of all of that, we try to make decisions based on factual information, not based on theory. Statistics and numbers contribute to the fact, but it is more than that. Sometimes we get accused of spending too much time doing all the analysis of that. Some will say, "Common sense will tell you. I know what the problem is." But collecting data and analysis will tell you if your common sense is right. (Liker, 2004, pp. 224-225)

To this extent the TPS category Problem Solving speaks to this issue through the following three sub-principles which identify the complexities associated with this concept.

- Continual organizational learning through Kaizen
- Go see for yourself to thoroughly understand the situation
- Make decisions slowly by consensus, thoroughly considering all options; implement rapidly.

Problem Solving can be viewed as a fragmented phenomenon in construction based on multiple detached operating divisions like excavation, electrical, and HVAC, which function independently from one another on construction sites adding to the challenge of a shared Problem Solving approach. IGLC research studies in this category contributed 2.1% to research studies between 1996 and 2009 as stipulated in Figure 30.



	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
All Studies	13	16	25	33	32	35	54	52	63	52	42	53	73	49
(PS) Studies	0	0	1	0	0	2	1	3	3	0	0	0	2	1

Figure 30. Breakdown of IGLC Problem Solving research studies between 1996 and 2009.

The compilation of the four TPS sub-categories with the 15 proxy categories provides an overview of the breakdown of the conference proceedings resulting from the content analysis of the 592 research studies analyzed (Figure 30) as formulated in sub-question four.

- Sub-question four: What lean related research categories within a percentage breakdown structure emerged from the IGLC conference research studies between 1996 and 2009?

Further analysis on the 19 research categories was conducted by dividing the 19 categories within a three group classification based on the percentage of their research representation as illustrated in Table 7 to determine the research trends over time within each category.

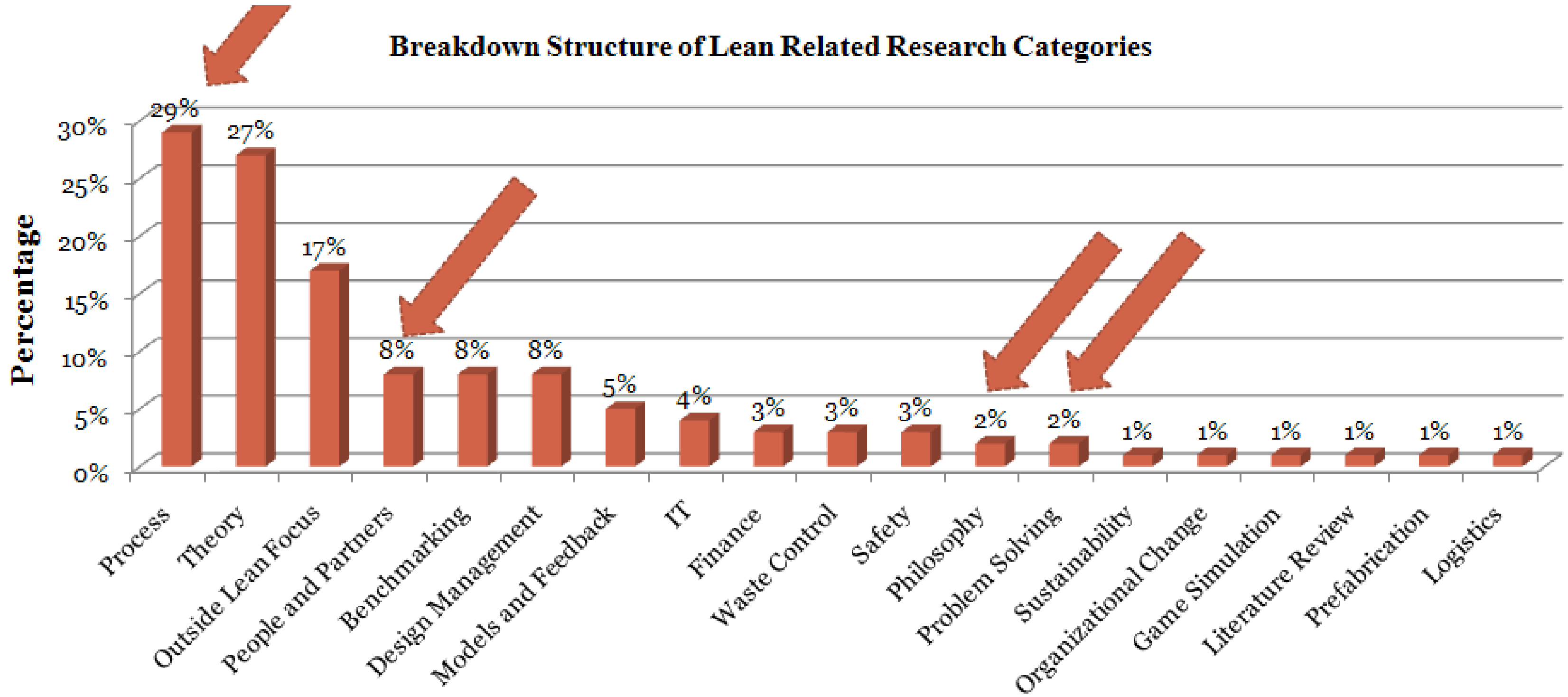


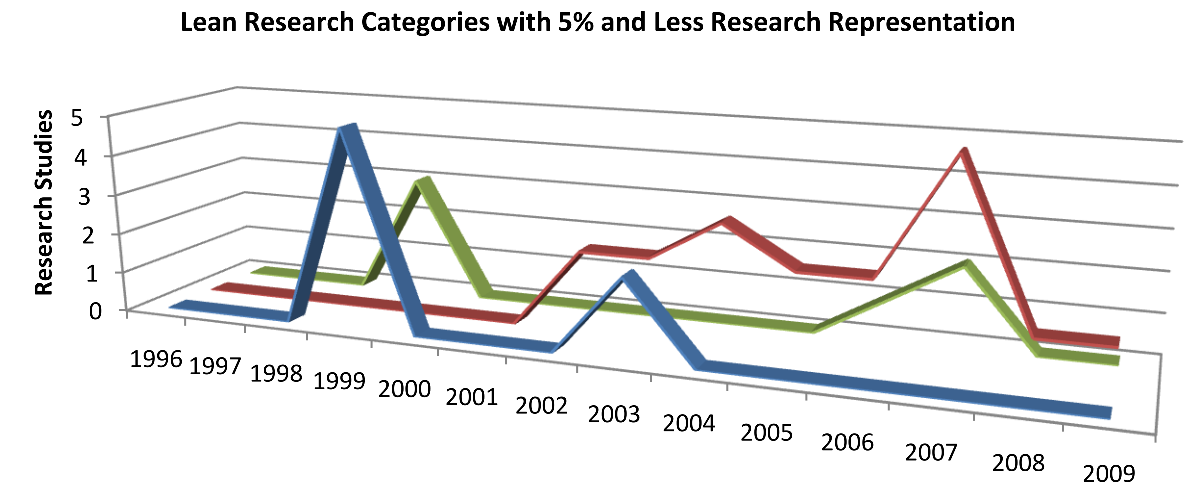
Figure31. An illustration of IGLC research studies classified within the 19 research categories with placing of TPS categories as indicated by arrows.

Table 7

Breakdown of IGLC Research Categories by Percentage of Representation

5% and less		Between 6% and 10 %		Greater than 10%	
Philosophy	2%	People and Partners	8%	Process	29%
Problem Solving	2%	Theory	9%	Outside Lean Framework	17%
Benchmarking	3%	Design Management	8%		
IT	4%	Models and Feedback	5%		
Sustainability	1%				
Organizational Change	1%				
Game Simulation	1%				
Finance	3%				
Literature Review	1%				
Waste Control	3%				
Prefabrication	1%				
Safety	3%				
Logistics	1%				

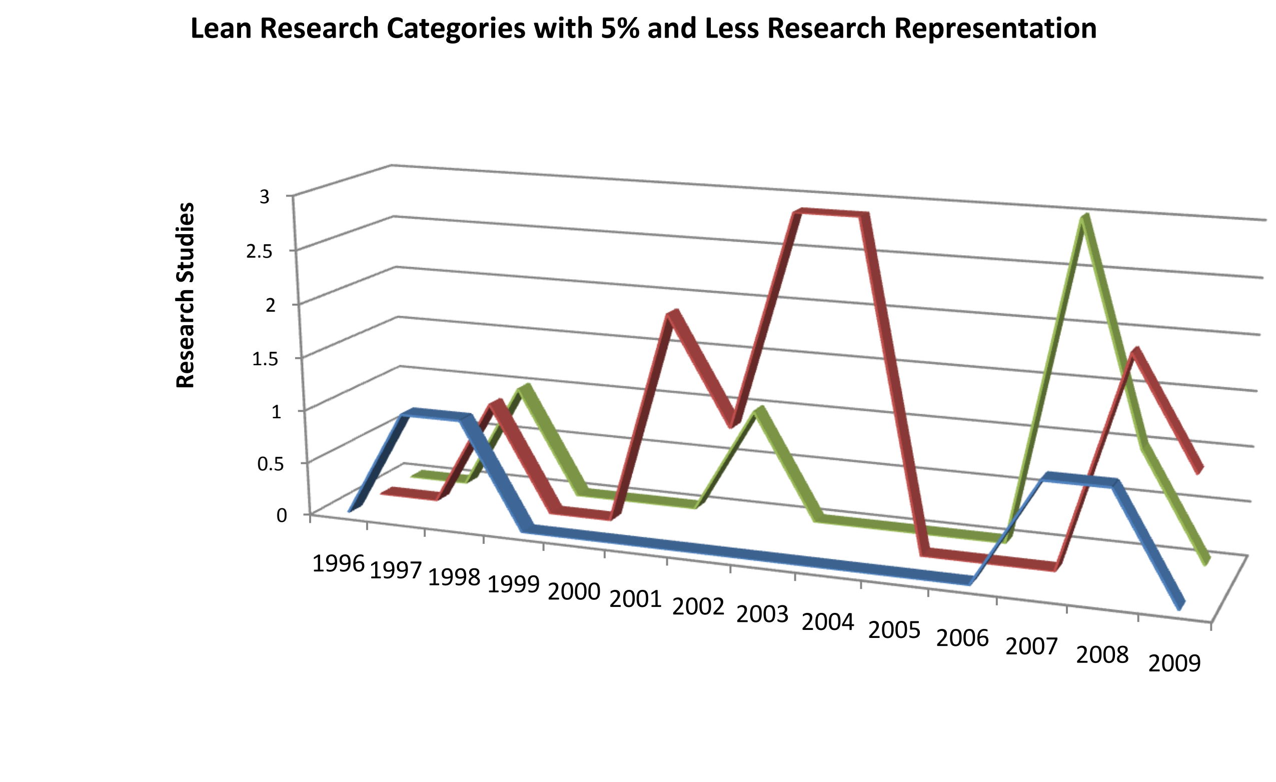
A category breakdown by percentage allowed the researcher to compare research categories with similar research representation. Fluctuations of research representation among categories were detected. The 5% and less category grouping was divided into three graph displays due to viewing difficulties if displayed on a single graph. Research study categories with less than a 5% representation among the IGLC research studies are shown in Figures 32, 33, and 34.



	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Literatrue Review	0	0	0	5	0	0	0	2	0	0	0	0	0	0
Safety	0	0	0	0	0	0	2	2	3	2	2	5	1	1
Logistics	0	0	0	3	0	0	0	0	0	0	1	2	0	0

Figure 32. An illustration of Literature Review, Safety, and Logistics research fluctuations observed in IGLC research studies between 1996 and 2009

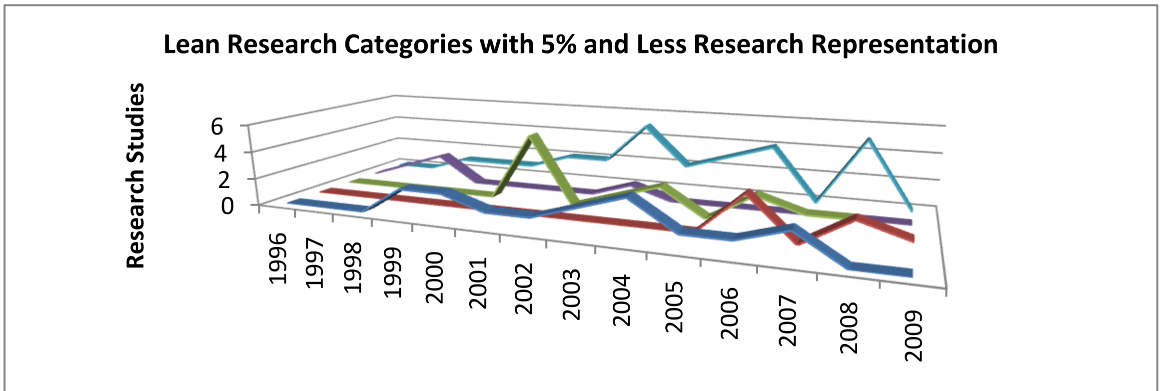
Figure 32 is representative of the categories Literature Review, Safety, and Logistics. Each category contributed less than 5% to the overall body of IGLC research studies. According to Figure 32, Literature Review and Safety demonstrated fluctuations as illustrated in the figure. Logistics was introduced to the construction research platform in 1998 with a contribution spike in1999; it flattened to a level of low research contribution in 2009. Figure 33 demonstrated similar research contribution patterns within Game Simulation, Problem Solving and Sustainability.



	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Game Simulation	0	1	1	0	0	0	0	0	0	0	0	1	1	0
Problem Solving	0	0	1	0	0	2	1	3	3	0	0	0	2	1
Sustainability	0	0	1	0	0	0	1	0	0	0	0	3	1	0

Figure 33. An illustration of Game Simulation, Problem Solving, and Sustainability research fluctuations observed in IGLC research studies between 1996 and 2009.

Game Simulation research demonstrated large fluctuations with periods of no research contributions during 1999 and 2006. Problem Solving and Sustainability research contributions had similar fluctuation patterns with periods of no research representation as illustrated in Figure 33. Figure 34 represents the remaining research categories of less than 5% research representation, which will be discussed next.

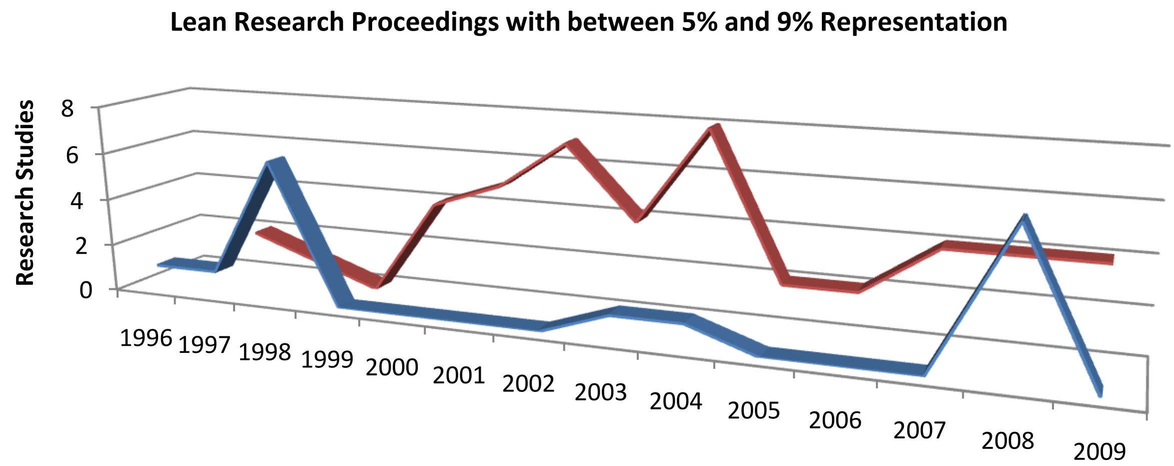


	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Waste Control	0	0	0	2	2	1	1	2	3	1	1	2	0	0
Prefabrication	0	0	0	0	0	0	0	0	0	0	3	0	2	1
Philosophy	0	0	0	0	0	5	0	1	2	0	2	1	1	0
Organizational Change	0	1	2	0	0	0	0	1	0	0	0	0	0	0
Information Technology	0	0	1	1	1	2	2	5	2	3	4	0	5	0

Figure 34. An illustration of Waste Control, Prefabrication, Philosophy, Organizational Change, and Information Technology research fluctuations observed in IGLC research studies between 1996 and 2009.

Waste Control had consistent research representation between 1999 and 2007. Prefabrication research in lean construction was introduced in 2005 and demonstrated low research contribution in comparison to other research categories. Philosophy had a spike in 2001. Organizational Change had less recent representation. Information Technology demonstrated a stable research contribution pattern during 1996 and 2009. Research fluctuations in categories with 5% and less representation demonstrated fluctuating research contributions between 1996 and 2009.

Research study categories with contributions between 6 and 9% representation among the IGLC research studies are shown in Figure 35.

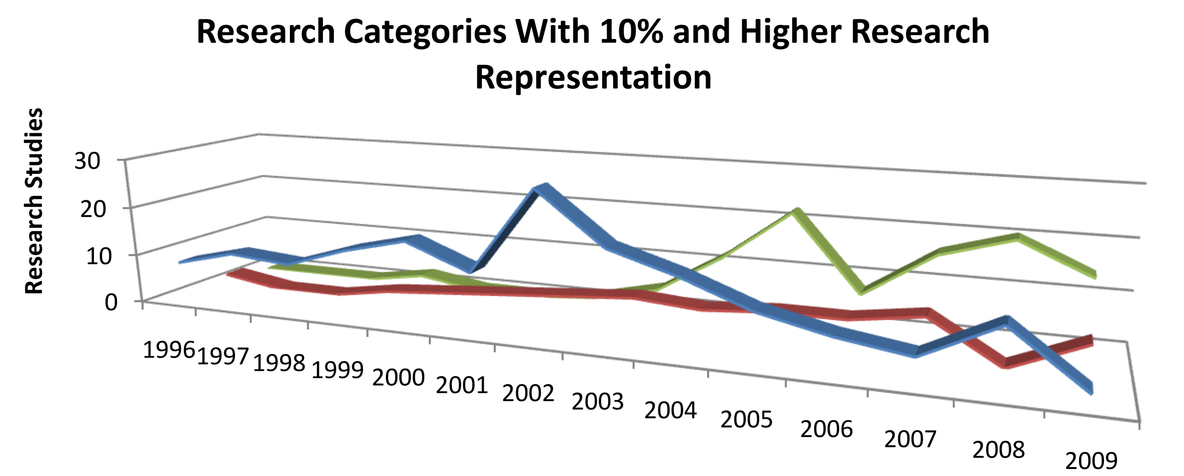


	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Benchmarking	1	1	6	0	0	0	0	1	1	0	0	0	6	0
Desing Management		2	1	0	4	5	7	4	8	2	2	4	4	4

Figure 35. An illustration of Benchmarking and Design Management research fluctuations observed in IGLC research studies between 1996 and 2009.

Figure 35 illustrated fluctuations and inconsistencies of research studies at IGLC representing between 5 and 9% of the proceedings at conferences during 1996 and 2009. Benchmarking was introduced to the construction research platform during 1998, was passive for three consecutive years, and then revived in 2003 and 2004 with strong research representation in 2008. Design Management has been known by the construction industry as an operation mechanism that holds great production benefit in support of lean thinking. Design Management fell to a zero contribution level during the 1999 IGLC conference in Berkley, California, and then spiked in 2004.

Research study categories with greater that 10% representation among the IGLC research studies are shown in Figure 36.



	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Process	8	11	10	14	17	12	29	19	15	10	7	5	12	2
Theory	2	0	0	2	3	4	5	6	5	6	6	8	0	6
Outside Lean Framework	0	0	0	2	0	0	1	4	12	22	7	16	20	14

Figure 36. An illustration of Process, Theory, and Outside Lean Framework research fluctuations observed in IGLC research studies between 1996 and 2009.

Process, Theory, and Outside Lean Framework were the three categories with the highest research representation at IGLC conferences between 1996 and 2009. Research outside the framework constituted research in areas not directly related to the TPS framework. A list of these studies is in Appendix C. Theory research in construction showed continual growth during the early years of lean research in construction. However, it had a steep decline in 2008 when Process resurged from a decline in the previous two years. Process research demonstrated the largest number of proceeding contributions among the 19 different research categories. Process contributions reached a peak in 2002 and have been declining since then. The *Last Planner* became known as a Process model developed by Ballard and Howell (2003). This model has been under constant refinement by various researchers due to its applied functionality in the field of construction. The application and acceptance of this model among construction companies might be a reason why Process research has declined over time.

The researcher further extrapolated upon the TPS and proxy categories to study each category's annual research representation at IGLC lean conferences.

- Sub-question five: What were the research trends between 1996 and 2009 within the lean related research categories?

Fluctuation patterns within each category (Figures 37 through 56) were discovered and are explained below.

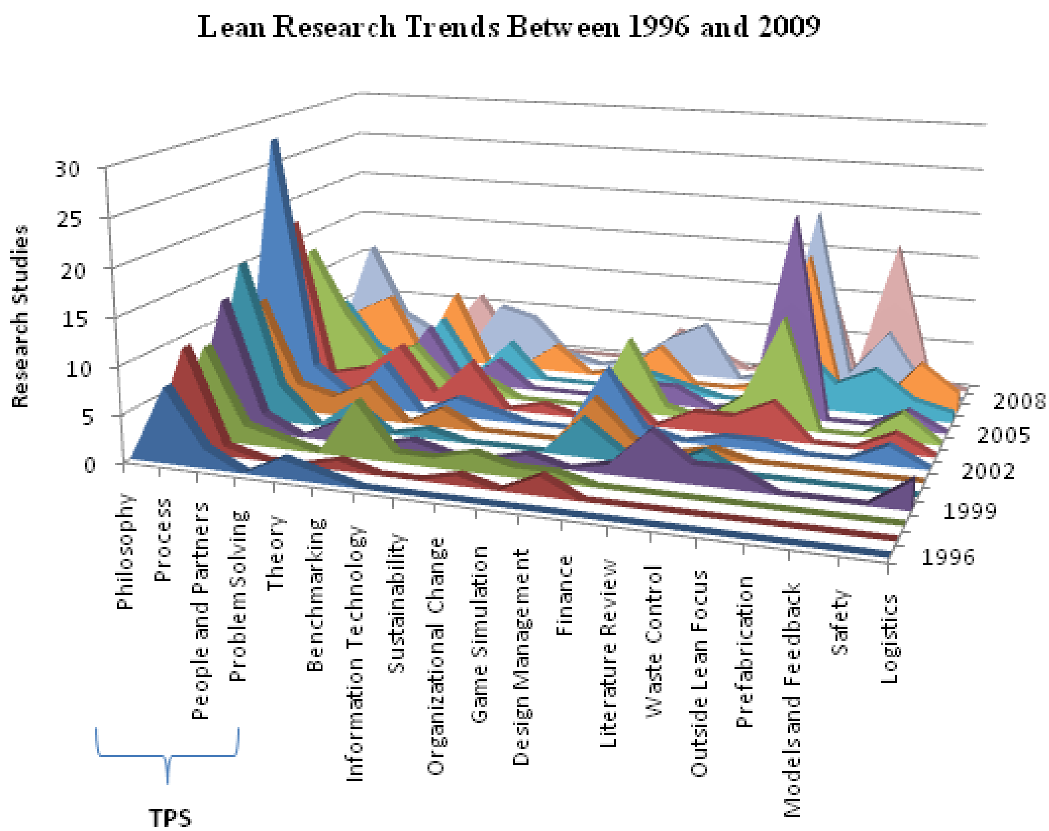
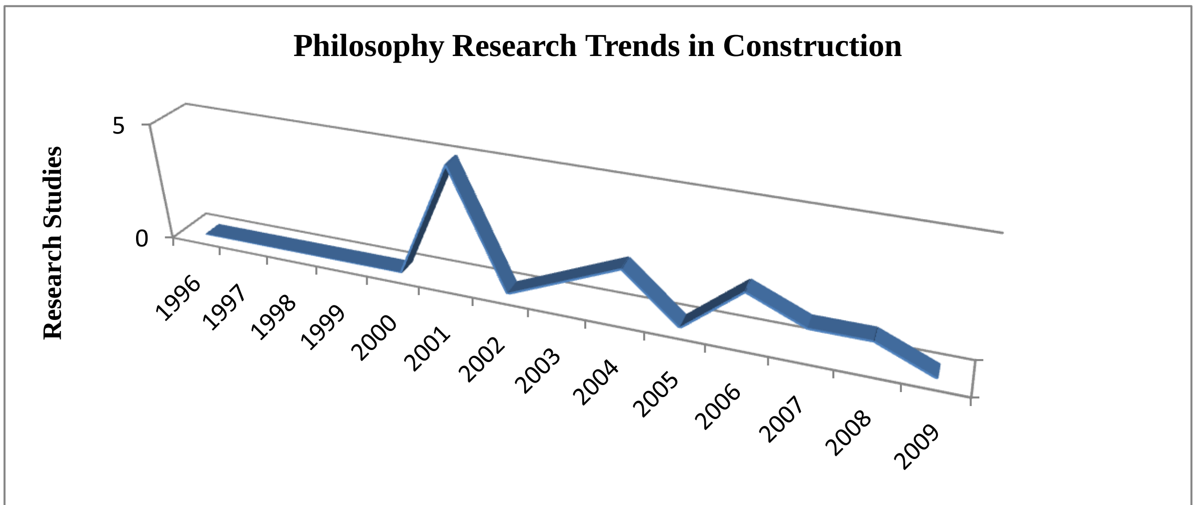


Figure37. An interpretation of lean research trends by category between 1996 and 2009.

Philosophy

Philosophy research in construction is concerned with long term thinking strategies in order to embrace lean thinking and to ensure buy-in by company leaders and workers for long-term success. Philosophy research in construction was first presented by researchers at the IGLC conference in Singapore in 2001(Figure 38). This segment of lean research constitutes 2% of IGLC research studies between 1996 and 2009. The importance of this category can be emphasized by Robert McCurry's statement on Philosophy: "The most important factors for success are patience, a focus on long-term rather the short-term results" (Liker, 2004, p. 71).

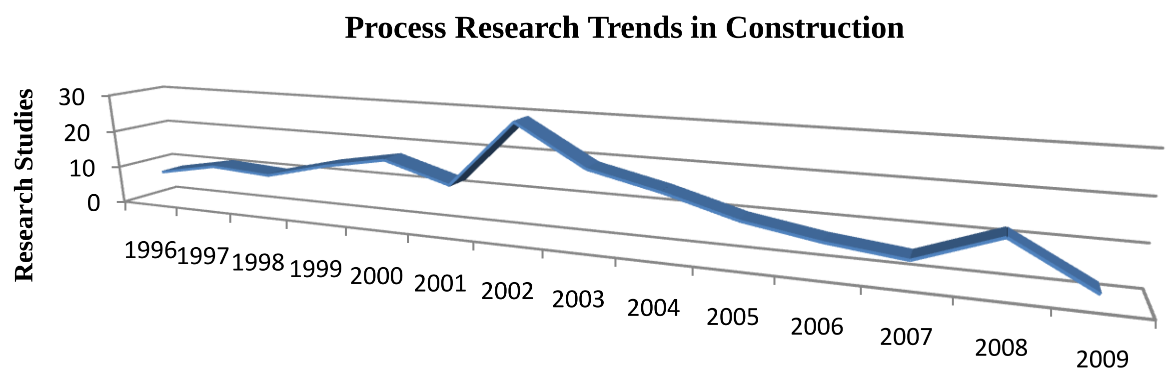


	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Philosophy	0	0	0	0	0	5	0	1	2	0	2	1	1	0

Figure 38. Representation of Philosophy research trends in lean construction extrapolated from IGLC research studies between 1996 and 2009.

Process

The applied nature of construction involves daily processes and the conversion of materials; therefore Process in construction can be viewed as a day-to-day necessity. As it is in manufacturing, Process in construction is a constant. The importance of Process in construction can be viewed as an ongoing phenomenon. According to the trend analysis, Process research in construction reached its peak during 2002 in Gramado, Brazil, where 16% of all conference proceedings for that year centered on Process. The researcher further stated that the majority of case studies presented at IGLC conferences were related to the application of Process models, predominantly *The Last Planner*. Process research in construction showed stable research representation at IGLC conferences between 1996 and 2009 as illustrated in Figure 39.

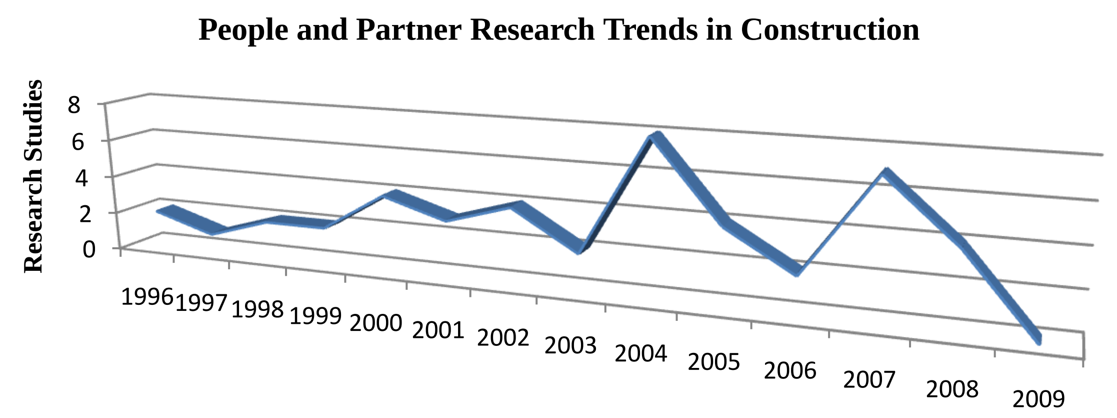


	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Process	8	11	10	14	17	12	29	19	15	10	7	5	12	2

Figure 39. Representation of Process research trends in lean construction as extrapolated from IGLC research studies between 1996 and 2009.

People and Partners

According to Alex Warner the importance of this category can be summed up as follows: "At Toyota, we simply place the highest value on our team members and do the best we can to listen to them and incorporate their ideas into our planning process" (Liker, 2004, p. xv). Lean research in this category contributed 7.6% to IGLC research studies between 1996 and 2009. The trend analysis revealed a higher than average research contribution during 2004 in Elsinore, California, and during 2007 in Michigan. These conferences might indicate that lean researchers in the U.S. strongly support research within this field. Zero proceedings in this category were presented during the 2009 conference in Taiwan. This research category maintained stable representation at IGLC conferences as illustrated in Figure 40.

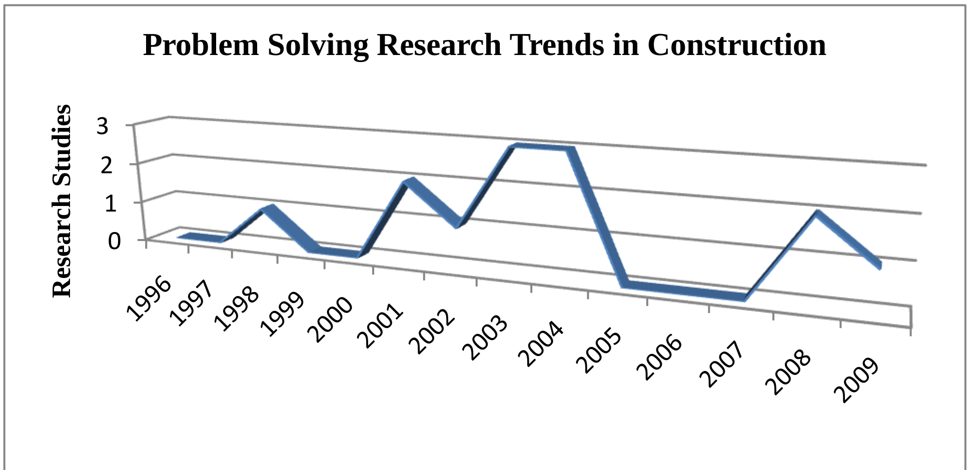


	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
People and Partners	2	1	2	2	4	3	4	2	8	4	2	7	4	0

Figure 40. Representation of People and Partner research trends in lean construction as extrapolated from IGLC research studies between 1996 and 2009.

Problem Solving

The category Problem Solving stresses the importance of continual operational learning, slow decision making, and understanding of the problem at hand. Lean research in this field contributed 2.1% of all IGLC research studies between 1996 and 2009. The trend analysis revealed three periods of no research, as illustrated in Figure 41, at conferences held in the U.S., Australia, and Chile. IGLC conferences draw from a global research audience allowing researchers to share across a wide research spectrum. Despite this wide researcher spectrum, research in this field lacked consistent representation during 1999, 2000, 2005, 2006, and 2007.

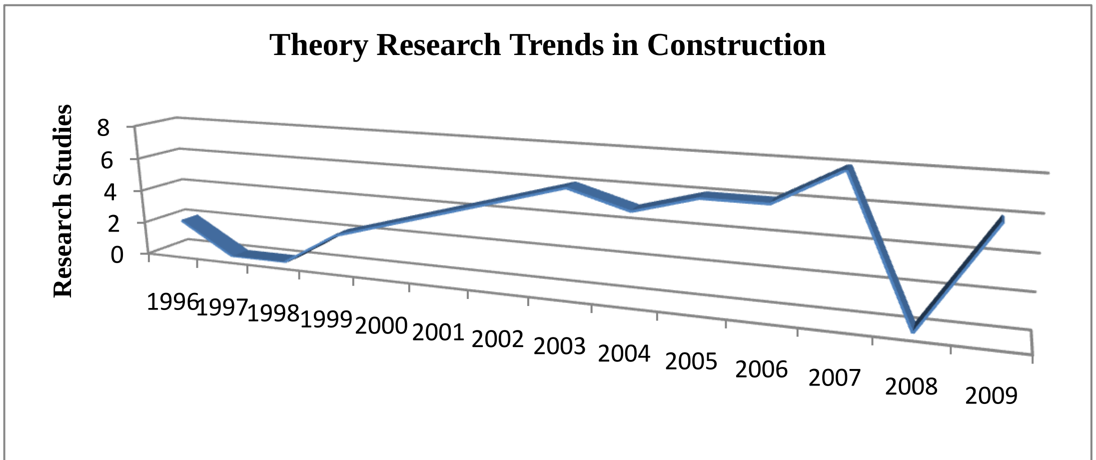


	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Problem Solving	0	0	1	0	0	2	1	3	3	0	0	0	2	1

Figure 41. Representation of Problem Solving research trends in lean construction as extrapolated from IGLC research studies between 1996 and 2009.

Theory

Theory building research in construction has received increased attention over the past 14 years. Prominent researchers in lean construction like Koskela, Ballard, Green, and Howell realized the importance for an applied theory in construction. Theory research constituted 8.9% of IGLC research studies between 1996 and 2009. Theory research had a gradual increase until 2007 as illustrated in Figure 42. During 2008, there were no Theory proceedings presented at the IGLC conference in Manchester, England. The importance of Theory research was introduced in Chapter Two as interplay between research and practice. Figures 13 and 14 (in Chapter 2) illustrate the interactive parts of Theory research: Conceptual Development, Operationalization, Application, and Confirmation or Disconfirmation.

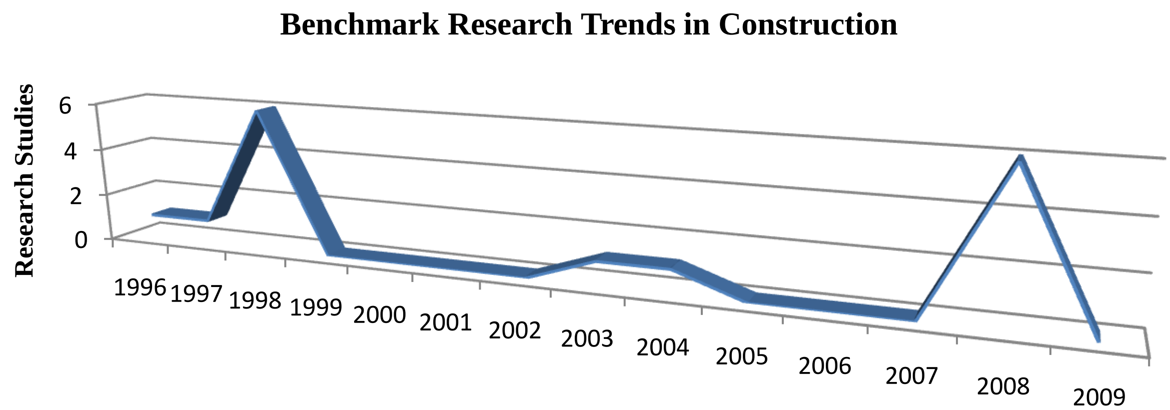


	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Theory	2	0	0	2	3	4	5	6	5	6	6	8	0	6

Figure 42. Representation of Theory research trends in construction research as extrapolated from IGLC research studies between 1996 and 2009.

Benchmarking

A Benchmarking category was created to accommodate research studies that did not qualify to be classified within the TPS framework. A definition for this category was provided in the chapter overview in Table 6. Research studies in this category compared construction processes and performances against that of other industries. This category constituted 2.7% of IGLC research studies between 1996 and 2009. The trend analysis indicated a research trough during the 1998 and 2008 IGLC conferences held in Manchester, England. The troughs are illustrated in Figure 43.

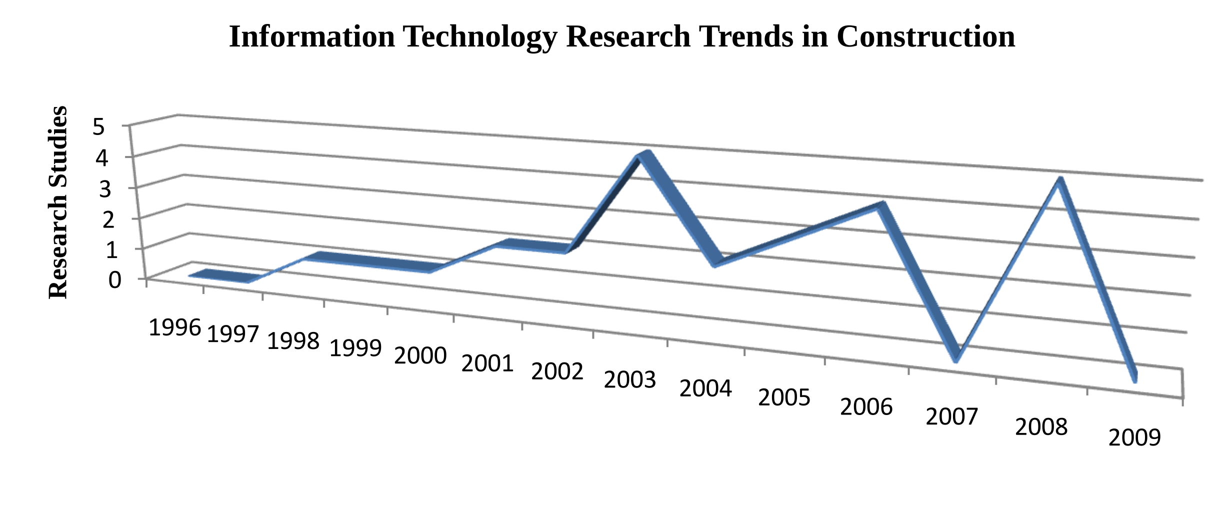


	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Benchmarking	1	1	6	0	0	0	0	1	1	0	0	0	6	0

Figure 43. Representation of Benchmarking research trends in construction as extrapolated from IGLC research studies between 1996 and 2009.

Information Technology

Information Technology in lean construction research was first introduced during the 1998 IGLC conference in Guaruja, Brazil. Information Technology research does not fit within the TPS framework and therefore the proxy category Information Technology was created. Research representation in this field experienced gradual growth since its introduction in 1998 as shown in Figure 44. The essence of research in this field centered around existing information technologies and how the application of these technologies in construction can add value to process outcomes in construction. Research in this field was mainly presented through construction case studies where information technology was applied. No research studies in this field were presented during the 2007 and 2009 IGLC conferences held in the U.S. and Taiwan.

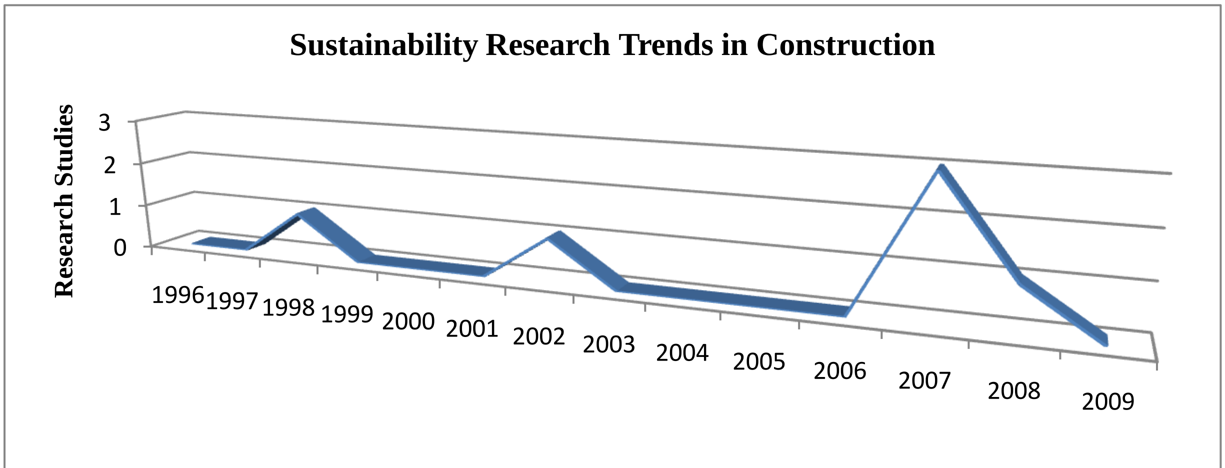


	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Information Technology	0	0	1	1	1	2	2	5	2	3	4	0	5	0

Figure 44. Representation of Information Technology research trends in construction as extrapolated from IGLC research studies between 1996 and 2009.

Sustainability

Research on sustainability issues represents 1% of the IGLC research studies between 1996 and 2009. Sustainability research did not fit within the TPS framework and was therefore classified as a standalone research category. The trend analysis indicated sporadic research representation in this category over time as illustrated in Figure 45. The researcher further indicated that the majority of Sustainability research initiatives were from Scandinavian countries including Finland, Sweden, and Denmark.

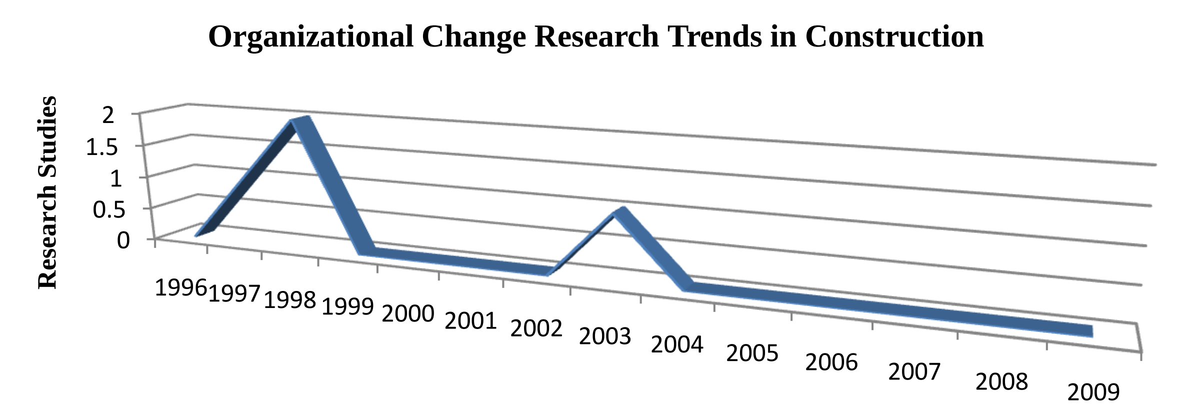


	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Sustainability	0	0	1	0	0	0	1	0	0	0	0	3	1	0

Figure 45. Representations of Sustainability research trends in construction as extrapolated from IGLC research studies between 1996 and 2009.

Organizational Change

A stand alone category for Organizational Change was created in order to accommodate lean research within this field. A definition for this category was provided in the general overview of this chapter stating that this category included research on companies that have undergone internal management transformation associated with lean thinking. In order to accurately frame this category the researcher had to distinguish between Organizational Change and long term thinking, which is part of the category Philosophy associated with the TPS framework. This category constituted 1% of IGLC research studies between 1996 and 2009. Not only did this category demonstrate low research representation, but it also demonstrated periods of no research contributions as illustrated in Figure 46.

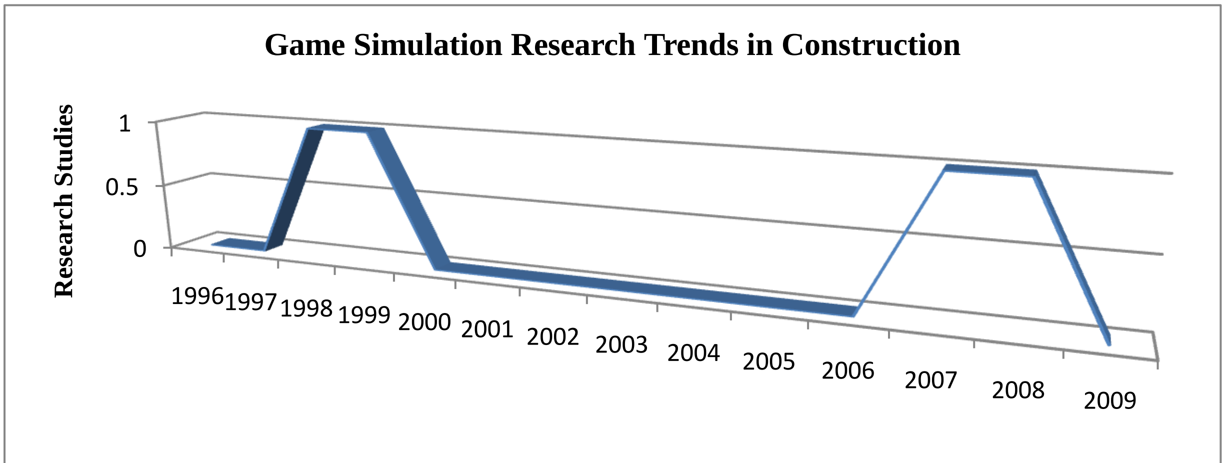


	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Organizational Change	0	1	2	0	0	0	0	1	0	0	0	0	0	0

Figure 46. Representation of Organizational Change research trends in construction as extrapolated from IGLC research studies between 1996 and 2009.

Game Simulation

A description of this category was provided in the general section overview of this chapter stating that Game Simulation research in construction consisted of various activities encountered in the construction field in the form of a game. Research in this field introduced the very concepts of lean thinking to students and audiences by way of playing a game. According to the trend analysis, Game Simulation research was first introduced during 1998 and 1999. Research contributions in this field represented 1% of all IGLC research studies between 1996 and 2007. Simulation research like the “Air Plane Game” encouraged more research contributions in Game Simulation during 2007 and 2008 as illustrated in Figure 47.

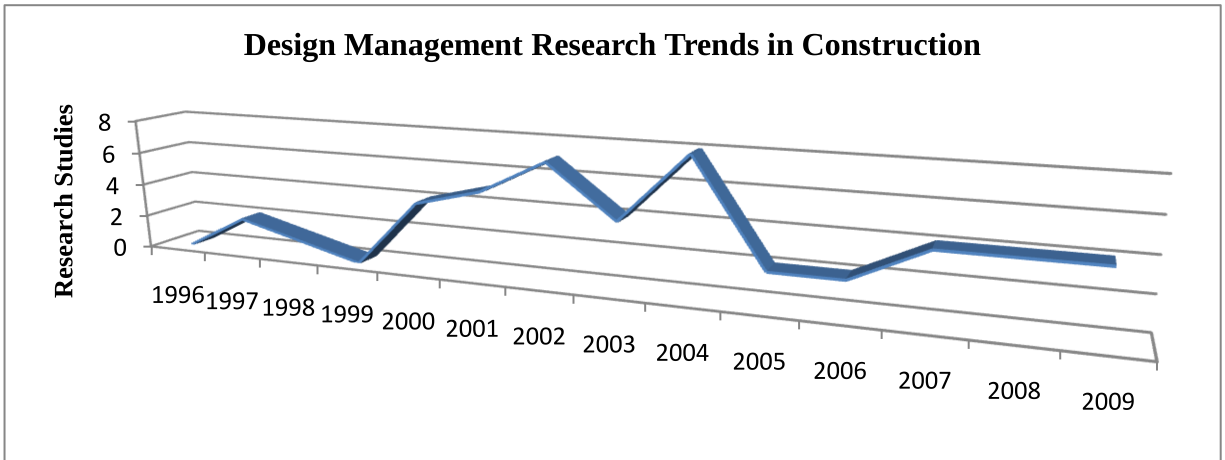


	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Game Simulation	0	0	1	1	0	0	0	0	0	0	0	1	1	0

Figure 47. Representation of Game Simulation research trends in construction as extrapolated from IGLC research studies between 1996 and 2009.

Design Management

The category Design Management was created by the researcher to distinguish research in this field from the closely related research category People and Partners, which is associated with the TPS framework. A description of this category was provided in the general overview section of this chapter stating that Design Management encompasses the integration of construction design into management and vice versa. This category constituted 8% of IGLC research studies with strong research representation between 2000 and 2008. A majority of these research contributions were based on case studies where the theoretical application of Design Management was implemented on construction projects, evaluated, and reported on. The trend analysis within this category can be viewed in Figure 48.

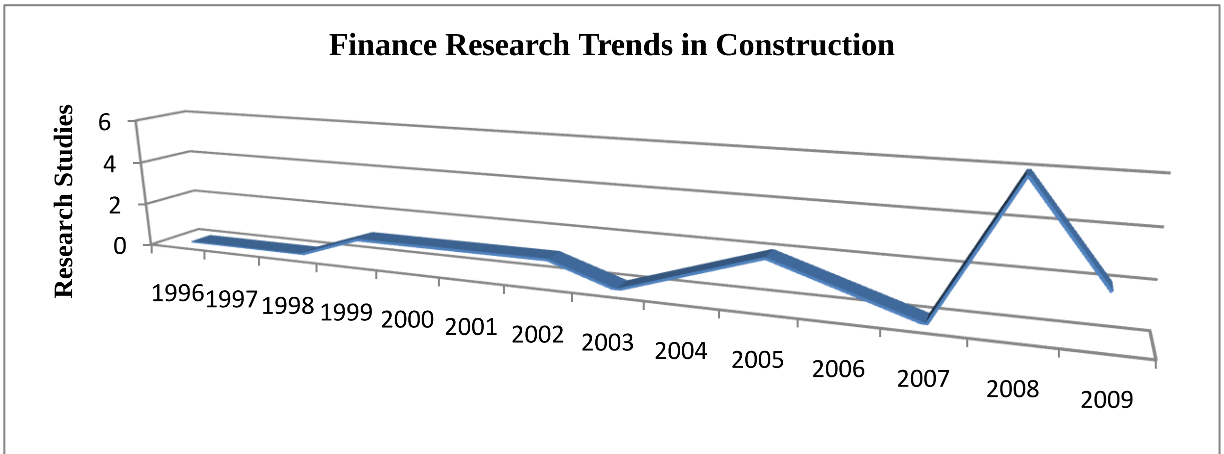


	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Design Management	0	2	1	0	4	5	7	4	8	2	2	4	4	4

Figure 48. Representation of Design Management research trends in construction as extrapolated from IGLC research studies between 1996 and 2009.

Finance

The TPS framework does not provide a category related to providing funds and capital on projects. For this reason a separate category was created under the heading Finance, which allowed the researcher to classify finance related research contributions into its own category. This category constituted 3% of IGLC research studies between 1996 and 2009. The trend analysis indicated a conservative but constant contribution of research in this field as illustrated in Figure 49.

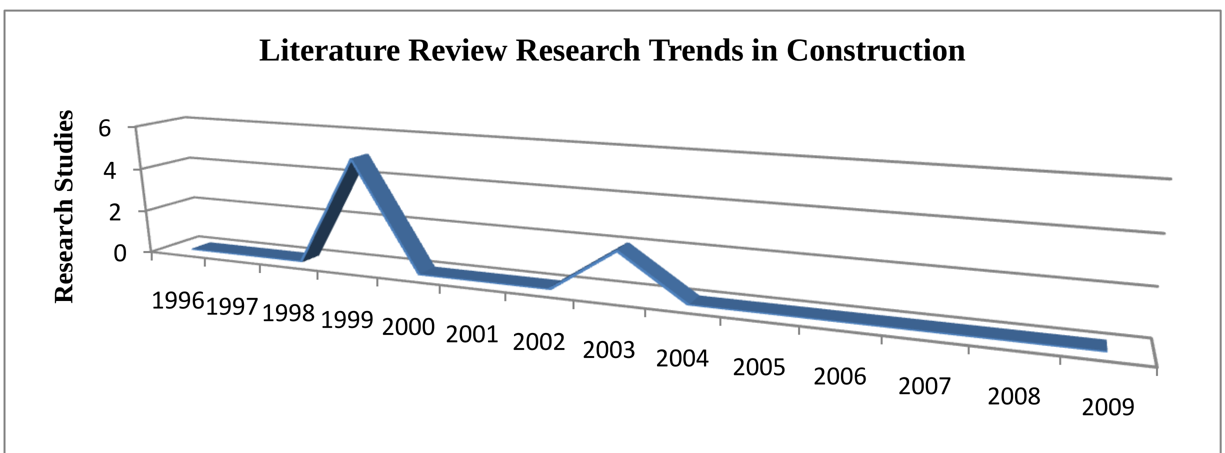


	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Finance	0	0	0	1	1	1	1	0	1	2	1	0	6	2

Figure 49. Representation of Finance research trends in construction research as extrapolated from IGLC research studies between 1996 and 2009.

Literature Review

This category included literature reviews of research on lean and critical points in construction which did not fall within the TPS framework outline. Research in this category constituted 1% of IGLC research studies between 1996 and 2009. The research analysis indicated a sporadic research pattern as illustrated in Figure 50.

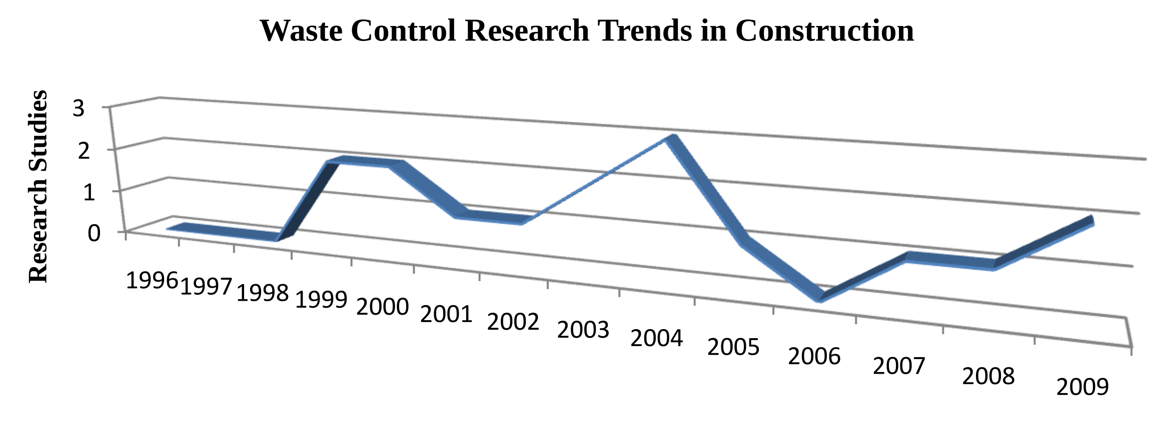


	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Literature Review	0	0	0	5	0	0	0	2	0	0	0	0	0	0

Figure 50. Representation of Literature Review research trends in construction as extrapolated from IGLC research studies between 1996 and 2009.

Waste Control

Research in this category emphasized operation measures against waste in construction. This research category represented 3% of IGLC research studies between 1996 and 2009. The trend analysis indicated a decline in research representation during the 2006 IGLC conference in Santiago, Chile, as indicated in Figure 51.

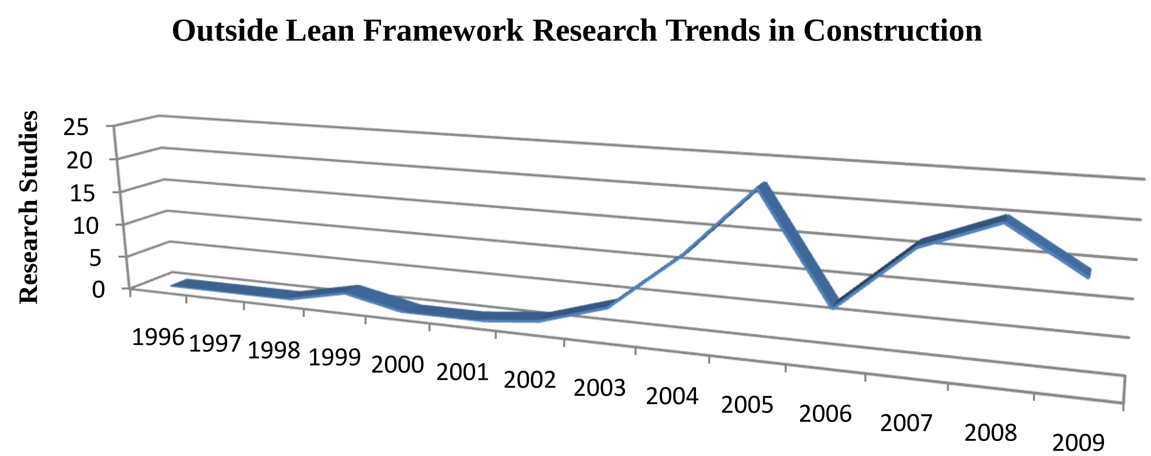


	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Waste Control	0	0	0	2	2	1	1	2	3	1	0	1	1	2

Figure 51. Representation of Waste Control research trends in construction as extrapolated from IGLC research studies between 1996 and 2009.

Outside Lean Focus

A research category for IGLC research contributions outside the TPS framework as well as the other 14 proxy research categories was created to assimilate research studies with no connection to TPS or lean. This category was defined as having no relevance to the four TPS categories or the 14 proxy categories in lean construction. A list of these studies is provided in Appendix C. This research category constituted 10% of IGLC research studies. The trend analysis indicated a dramatic research increase in this field during 2003 and beyond as illustrated in Figure 52.

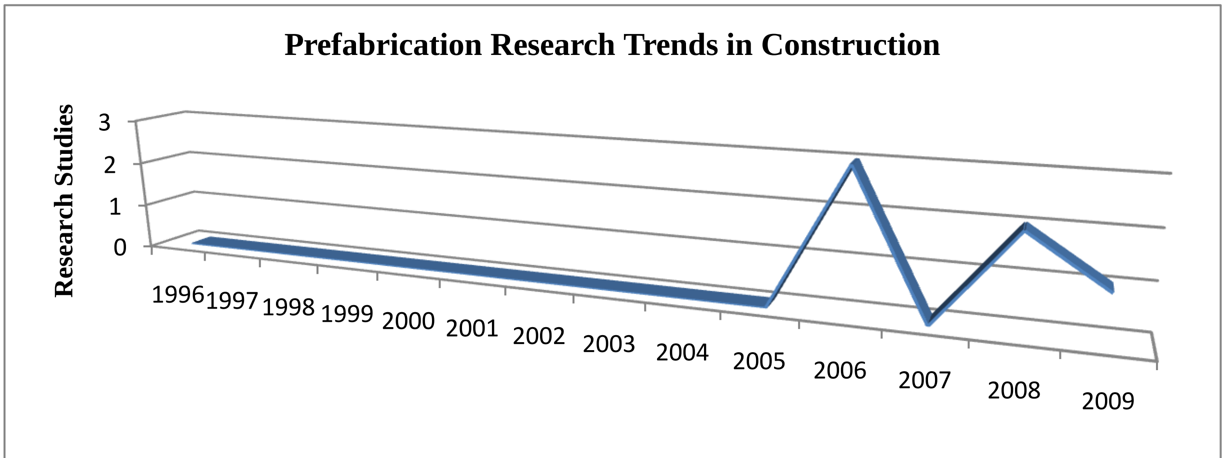


	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Outside Lean Framework	0	0	0	2	0	0	1	4	12	22	7	16	20	14

Figure 52. Representation of Outside Lean Framework research trends in construction as extrapolated from IGLC research studies between 1996 and 2009.

Prefabrication

This category encompassed research related to the manufacturing of sections of a building at factory locations. This section constituted 1% of IGLC research studies between 1996 and 2009. Prefabrication in construction is not a new phenomenon. The research studies analyzed discussed prefabrication in the context of lean. Therefore, the creation of a proxy category for this set of studies was justified. Figure 53 shows the trend of research in this field at IGLC conferences that began in 2006 and continued.

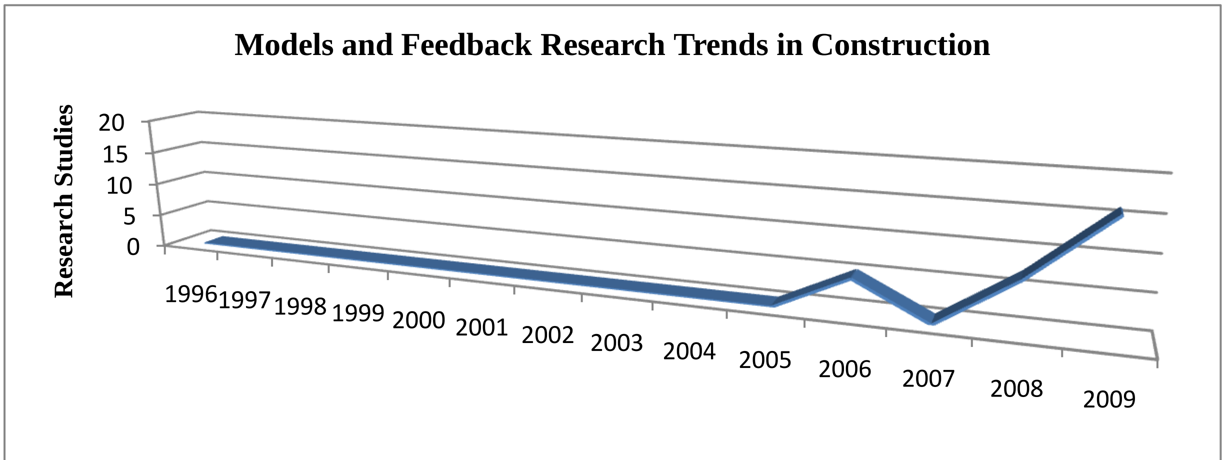


	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Prefabrication	0	0	0	0	0	0	0	0	0	0	3	0	2	1

Figure 53. Representation of Prefabrication research trends in construction as extrapolated from IGLC research studies between 1996 and 2009.

Models and Feedback

A description of this category was provided in the general overview section of this chapter. The research studies in this category discussed the creation, implementation, and results of lean models in construction. This category contributed 5% of IGLC research studies between 1996 and 2009. The trend analysis indicated that research in this field was first introduced during 2006 as illustrated in Figure 54.

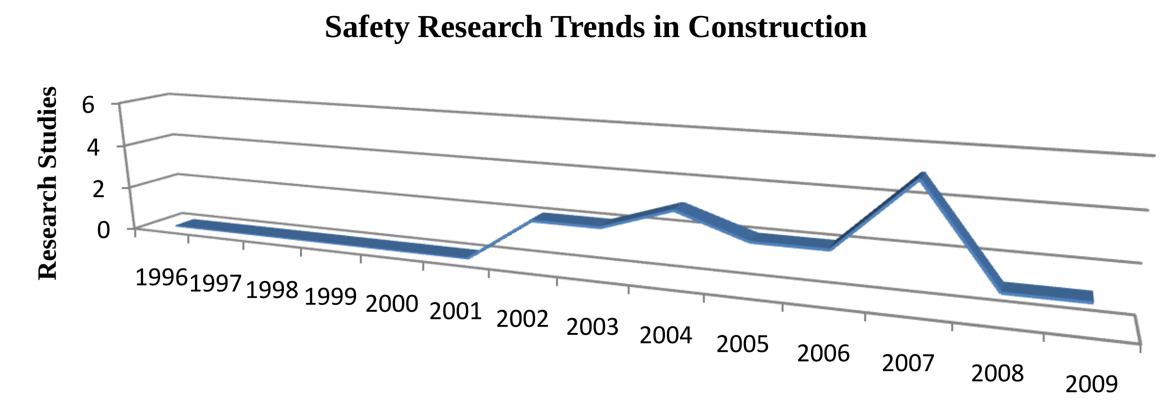


	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Models and Feedback	0	0	0	0	0	0	0	0	0	0	5	0	7	16

Figure 54. Representation of Models and Feedback research trends in construction as extrapolated from IGLC research studies between 1996 and 2009.

Safety

Safety research in construction is concerned with injury and death prevention measures. The researcher stated that there was not a direct link to the TPS framework in this category; however, safety systems in construction inevitably contribute to more desired production outcomes such as improved profitability and schedule maintenance. This category constituted 3% of IGLC research studies between 1996 and 2009. The trend analysis indicated that Safety research linked to lean in construction was first introduced during 2002 as illustrated in Figure 55.

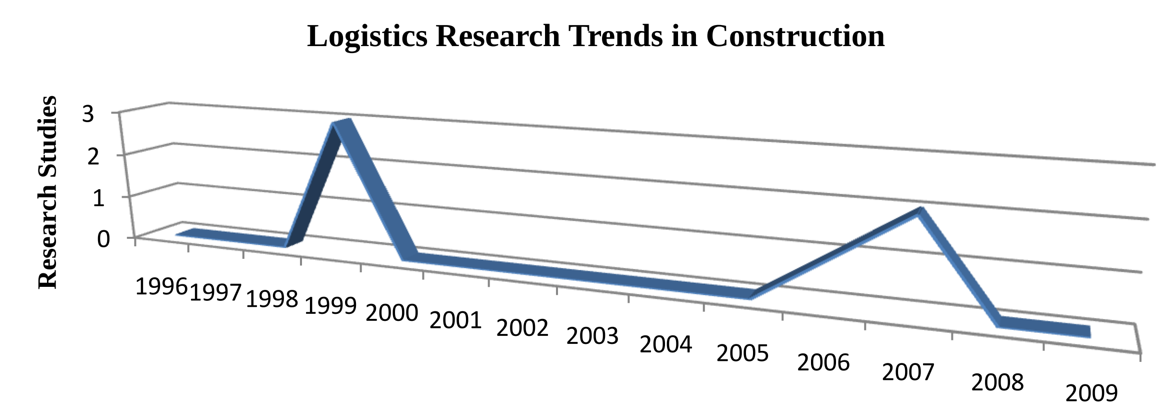


	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Safety	0	0	0	0	0	0	2	2	3	2	2	5	1	1

Figure 55. Representation of Safety trend patterns in lean construction research as extrapolated from IGLC research studies between 1996 and 2009.

Logistics

A description of this category was provided in the general overview section of this chapter. Logistics is the category dedicated to research in the handling of operations including site management in construction. This category constituted 1% of IGLC research studies between 1996 and 2009 as illustrated in Figure 56.



	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Logistics	0	0	0	3	0	0	0	0	0	0	1	2	0	0

Figure 56. Representation of Logistics research trends in construction as extrapolated from IGLC research studies between 1996 and 2009.

The researcher analyzed 592 IGLC research studies during the course of this study. Each research study was classified within a specific research method category based on the research method used in conducting each study.

- Sub-question six: What research methods were used in IGLC research studies between 1996 and 2009?

These research method categories included General Qualitative Research, Case Studies, Action Research, and Structured Interviews. A description of each research methods category is included in Table 8.

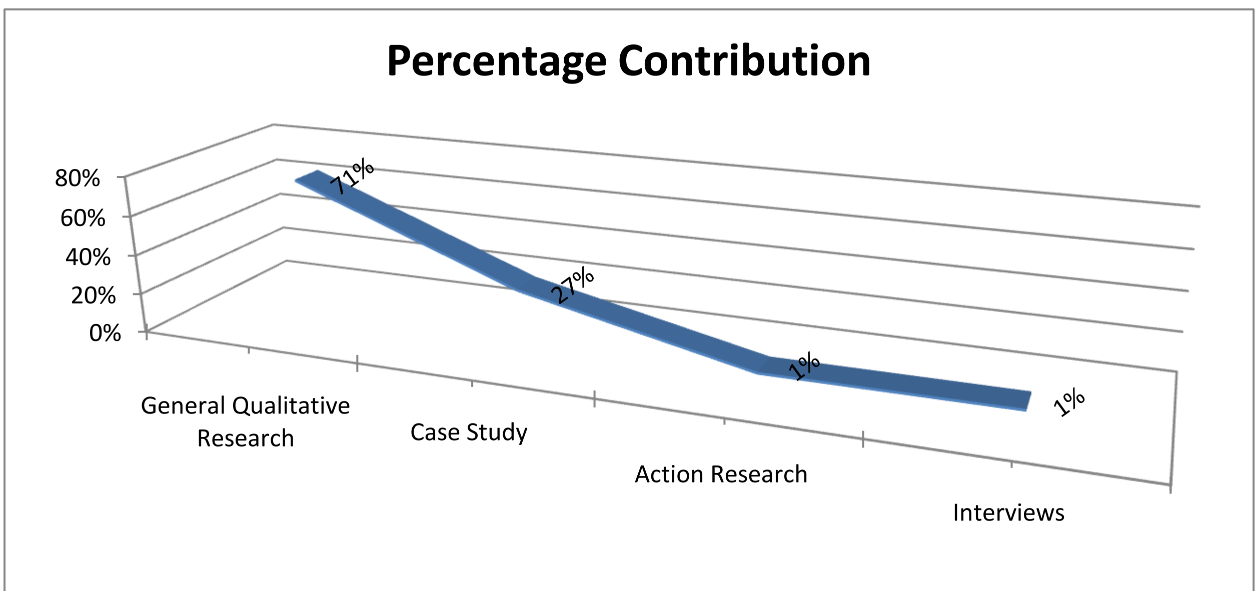
Table 8

An Overview and Description of the Different Research Methods Categories Used in IGLC Lean Construction Research Between 1996 and 2009

Research Method	Definition	Applied in this Study
General Qualitative Research	Qualitative research provides detailed descriptions and explanations of a phenomenon studied rather than providing and analyzing statistics.	In this study lean researchers created an inquiry around the phenomenon of lean theory in construction.
Case Study	Case Study research is a type of qualitative research and is based on an in-depth investigation of a single individual, group, or event to explore causation in order to find underlying problems.	In this study lean researchers applied lean theory on projects in the construction field.
Action Research	Action research is a type of qualitative research and is a reflective process of progressive problem solving led by individuals working with others in teams or as part of a "community of practice" to improve the way they address issues and solve problems.	In this study lean researchers engaged in problem solving methods in an attempt to improve construction processes.
Structured Interviews	Structured interviews, another form of qualitative research, ask people questions during an interview process. The interviewer usually has a framework of themes to be explored.	In this study lean researchers interviewed various players within the construction field.

A detailed explanation of the theoretical underpinning of lean theory was introduced in Chapter Two. Four research method categories were identified allowing the researcher to classify all proceedings within one of the four categories as listed in Table 8. Of the IGLC research studies analyzed, 71% were classified in the General Qualitative Research category by definition as illustrated in Figure 57. Twenty-seven percent of IGLC research studies were classified as case studies based on the definition provided in Table 8. The use of case studies in research allowed lean researchers and practitioners in construction to apply and explore lean theory in the field according to the Lynham's Research and Theory Development Model as discussed in

Chapter Two. The Action Research category was established based on reflective processes in lean construction where researchers engaged in ways to improve how construction companies address operation and site issues. Research in this category was site based where consultants, academics, and practitioners functioned in harmony during the course of a project in progress. This research method category contributed 1% to IGLC research studies as illustrated in Figure 57. The Structured Interviews category was created to accommodate lean research through an interview process. The essence of this research category involved interviewing field personnel, middle management, and upper management in construction companies. This research method category contributed 1% to IGLC research studies as illustrated in Figure 57.



	General Qualitative Research	Case Study	Action Research	Interviews
Percentage Contribution	71%	27%	1%	1%

Figure 57. Research methods used in lean construction. Four kinds of research methods used in lean research as presented at IGLC conferences between 1996 and 2009.

- Sub-question seven: What has been the level of contribution of different countries to IGLC research studies between 1996 and 2009?

IGLC conferences are not limited to one location, allowing conferences to be held in a different country each year. A table listing past conference locations was provided in Chapter Three (Table 5). The researcher reported that attendance levels at IGLC conferences varied depending on conference location. An example of such an attendance pattern occurred during 1998 and 2002 when the IGLC conference was held in Brazil. During these conferences, strong research support was observed from South American countries like Brazil, Argentina, and Chile. A similar attendance pattern was experienced during the 2009 IGLC conference in Taiwan, which drew strong conference support from countries like India, Singapore, and Thailand. Despite these fluctuations, a few countries demonstrated continued strong research support as illustrated in Figure 58. A research study might have authors from multiple countries; therefore determining the country of origin for a study was difficult. The researcher classified these research studies according to the country location of the first author. The United States, Brazil, United Kingdom, Chile, and Denmark were listed as the five largest contributors to construction lean research as illustrated in Figure 58.

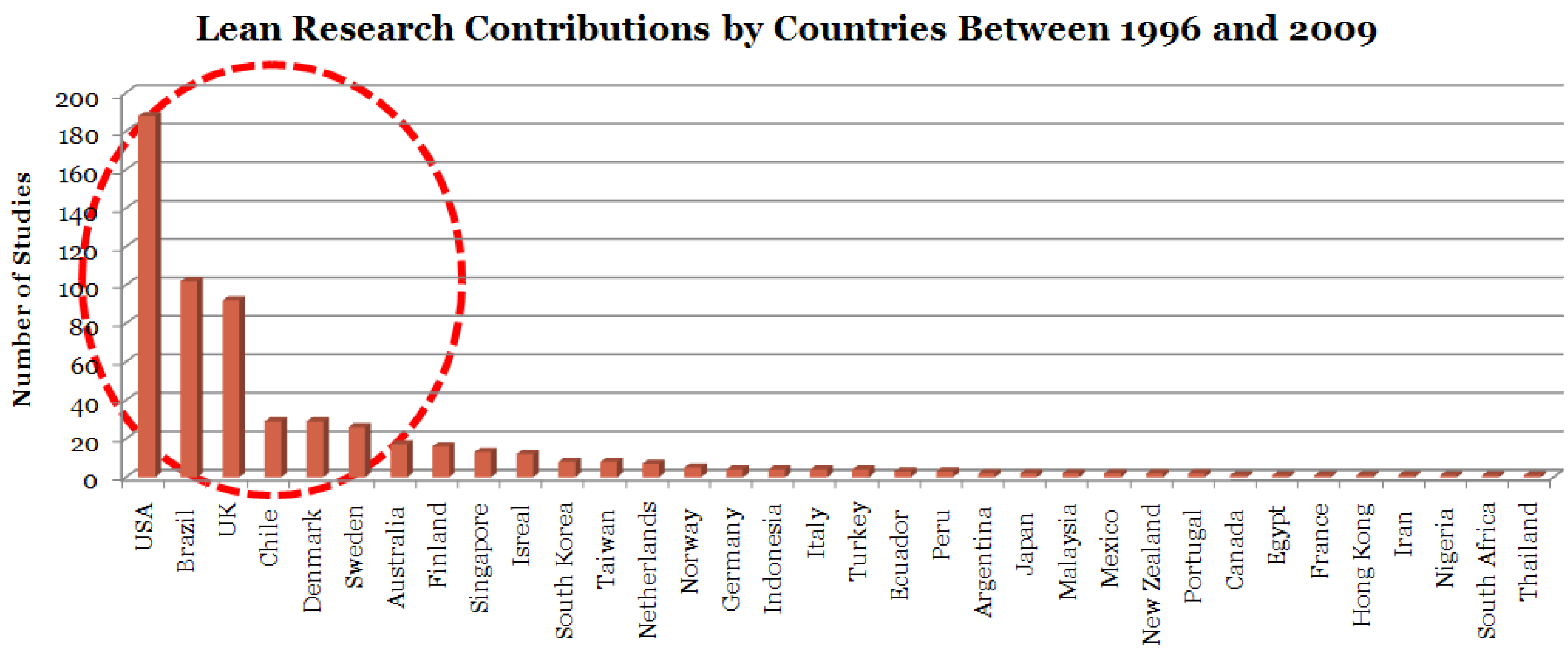


Figure 58. Lean research contributions between 1996 and 2009: U.S., Brazil, and U.K. have the highest representation as indicated by circle.

CHAPTER FIVE: CONCLUSIONS AND DISCUSSION

Introduction

This chapter provides a summary of the study as well as important conclusions drawn from the data presented in the previous chapters. In addition, this chapter provides discussion on implications for action and recommendations for further research.

Summary of the Study

This study began as an exploratory investigation through content analysis, investigating IGLC research studies between 1996 and 2009. The following is a "compact narrative" on the study.

1. The problem is that there have been few, if any, empirical research studies that have examined the existing lean construction literature analyzing it relating to the TPS framework.
2. The purpose of this study was to foster awareness of lean research in construction and to determine how accurately lean research studies in construction as shown by IGLC conference proceedings align to the TPS theoretical framework.
3. The overarching research question in this study asked: Are IGLC research studies in lean construction representative of the TPS theoretical framework as put forth in *The Toyota Way* (Liker, 2004)? Seven additional sub-questions were formulated in support of the

overarching research question. The following is an abbreviated list of the sub-questions, as was introduced in Chapter One.

a. One: Percentage of studies classified within the TPS framework.
b. Two: Distribution of studies into subcategories.
c. Three: Trend of contribution in subcategories.
d. Four: Percentage breakdown of lean related research categories.
e. Five: Trends within lean related research categories.
f. Six: Research methods used in the analyzed studies.
g. Seven: Level of contribution of countries to research.

4. The design of this study focused on the analysis of texts, which in this case were IGLC research studies from 1996 through 2009. Content analysis was chosen as the preferred methodology in conducting the analysis. Content analysis utilizes a set of procedures to make valid inferences from texts to answer research questions. The study followed a linear research sequence utilizing content analysis to reveal the research focus of a group, which in this case consisted of construction researchers and practitioners, and their research contributions, to determine if their studies were aligned to the TPS framework.

5. An IGLC database consisting of 592 studies from 1996 through 2009 was compiled. The IGLC study database was formatted and imported into NVivo, a qualitative data analysis (QDA) software program designed for working with rich text-based and/or multimedia information, where deep levels of analysis on small, medium, or large volumes of data are required. A total of 592 IGLC research studies were analyzed for exploratory findings, where each of these studies was aligned against the TPS framework. For a research study to be aligned within the TPS framework it had to conform to the TPS

framework, which encompasses 14 principles within four categories. Each study was read and aligned against the TPS framework according to its research intent. Studies that did not conform to the four categories of TPS were classified into one of 15 proxy categories. Proxy categories are related lean research categories created by the researcher. These categories developed through the course of the analysis as a way of grouping together IGLC research studies that did not align to the TPS framework. The proxy categories allowed the researcher to classify each of the 592 IGLC research studies within a specific category despite non-conformance to the TPS framework. Drawing on the results of the study as seen in Chapter Four, research recommendations were arrived at concerning the lean research platform in construction.

6. The outcome of the content analysis revealed that IGLC lean research studies in construction between 1996 and 2009 did not revolve exclusively around the TPS framework. Of 592 analyzed research studies only 241 (40%) could be classified within the TPS framework while the remaining 351 (60%) were classified outside the TPS framework in one of 15 proxy lean research related categories.

Findings Related to the Literature

The results of the study can be linked to the literature as reviewed in Chapter Two in the following two ways: links between the TPS and the construction lean frameworks, and applied versus conceptual research.

Link between the TPS and the Construction Lean Frameworks

Based on literature introduced in Chapters One and Two, researchers struggle to implement lean verbatim from TPS to the construction operating platform. This struggle is at least in part due to the different operating platform in construction which has additional features with which to contend as opposed to static manufacturing, as was explained in Chapter Two (Koskela, 2002). The literature further emphasized that although lean production is not viewed as fully applicable to the construction operating platform, its underlying concept can be utilized beyond the production level (Womack et al., 1990).

Results obtained in this study demonstrated that there were selective research agendas and interests among lean researchers in construction. IGLC conferences offer an open research forum allowing researchers to contribute within their respective research fields. Despite this open forum, or possibly because of it, multiple TPS principles lack research representation at these conferences. One example is illustrated in Figure 59, compiled from the last IGLC conference in Taiwan in 2009, where 96% of research studies were not linked to the TPS framework.

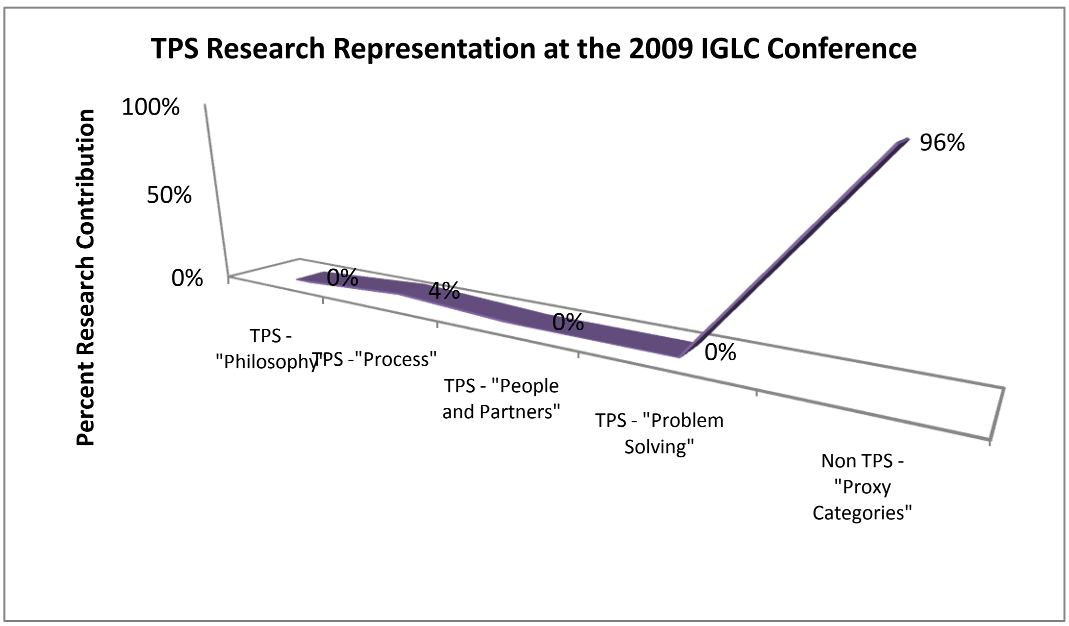


Figure 59. TPS research representation at the 2009 IGLC Conference. Illustrations of research deviations from the TPS framework in construction lean research.

The study further indicated that lean research deviated from the TPS framework over time. This provides support for the notion that a need for lean related research exists outside the

TPS framework for broader applied functionality to the construction operating platform. This indicates that research in lean construction has surpassed confinement to the TPS framework, which indicates the need for lean research unique to the construction industry's own operating platform.

Because a majority of research studies focused on topics outside the TPS framework, the researcher believes there is a need for lean research outside the TPS framework in construction. In, *Building the Bridge as you Walk on It*, Robert Quinn (2004) pointed out that it is not possible to duplicate the success of any other company by merely imitating its techniques. Perhaps this is why so many construction companies have failed to implement lean principles in their operating platforms. Quinn further states that companies imitate techniques originating elsewhere but fail to live in the fundamental state of vested interest, as did the person or company who originated the technique. Operations models like the TPS framework are valuable; however, companies cannot learn to make operations work if they are not challenged in the same way originators were (Quinn, 2004). The dilemma in construction is that companies seem to want to copy the outward appearance of what Toyota is doing and has done with the TPS framework in their day-to-day operations, in hopes of copying their success.

The Machine that Changed the World (Womack et al., 1990) introduced a foundation framework of lean theory in construction. According to the authors, lean theory in construction consists of an array of complex concepts—continuous improvement, flattened organizational structures, teamwork, elimination of waste, efficient use of resources, and corporate supply chain management—which outline the theoretical underpinning of lean construction as emulated from the TPS framework. Figure 60 illustrates the differences between the TPS and construction lean frameworks and reveals that the TPS framework is a more extensive framework than the construction lean framework introduced by Womack et al. (1990). Construction researchers pursued a research agenda applicable to the need of the operating platform in construction by contouring their research agendas to the broader needs of the industry rather than staying true to the TPS framework.

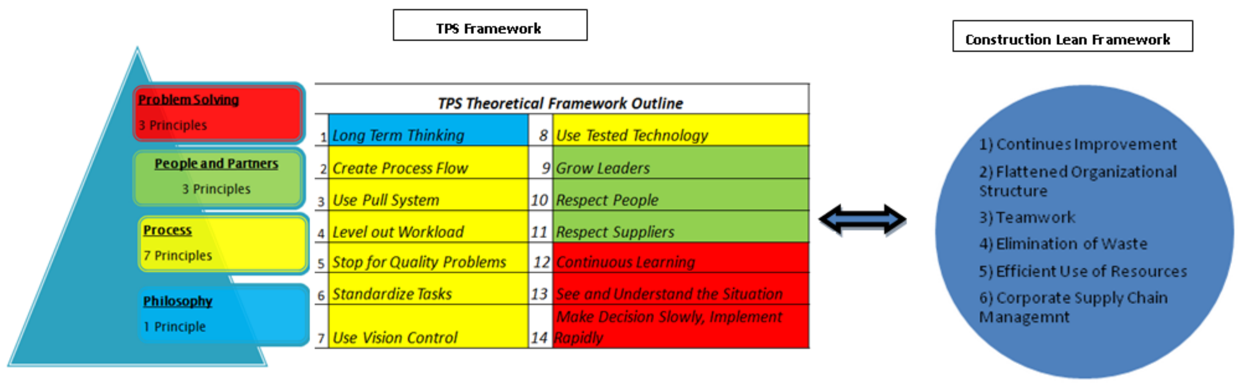


Figure 60. TPS and Construction Lean Theory Frameworks: Alignment of the TPS and Construction Lean Theory Frameworks.

In addition to research outside the TPS framework,

> …the weak tie of lean research in construction is further based on the increasing influence of commercially vested interests over the publicly-funded research agenda which means a balanced portfolio of research is unlikely to occur. (Green, 1999, p.136)

This lends insight into the possible motivation behind research, which oftentimes is the ability to procure funding. The following discusses the difficulties in lean construction research attempts as extrapolated from the results of this study based on the research studies analyzed.

Applied Versus Conceptual Research

Confusion and disagreement about what comprises lean construction theory and how it can be measured operationally exists in the construction industry, thus creating difficulty in lean's application to the construction platform (Green, 1999). Lean construction research started gaining recognition in 1993 with the formation of the IGLC. According to da CL Alves & Tsao

(2007), the IGLC conference was often a venue of choice for lean construction researchers as well as for practitioners to display their work and discuss different facets of lean construction research and implementation. This open research forum accommodated a wide range of research interests.

Within the analyzed database a total of four prominent research methods were identified in support of lean research in construction as was indicated in Figure 57. The underpinning of lean construction is based on borrowed production and quality theories as was illustrated in Figure 11. The study analysis revealed that the 592 analyzed research studies were qualitative in nature based on their research underpinning. Lynham (2002) stated that research requires two kinds of expertise as it pertains to the field of inquiry: knowledge and experience, as was explained in Chapter Two. Therefore, in fields like construction, interplay between theory, research and practice should form the foundation of theory development in a research context. Figure 61 demonstrates the alignment of applied lean research within the Operationalization phase in the Theory Development Model which was introduced in Chapter Two. The 70% Theory Base Research segment does not apply to the Operationalization phase of the Theory Development Model. Operationalization is an important aspect of research in applied theory (Lynham, 2002).

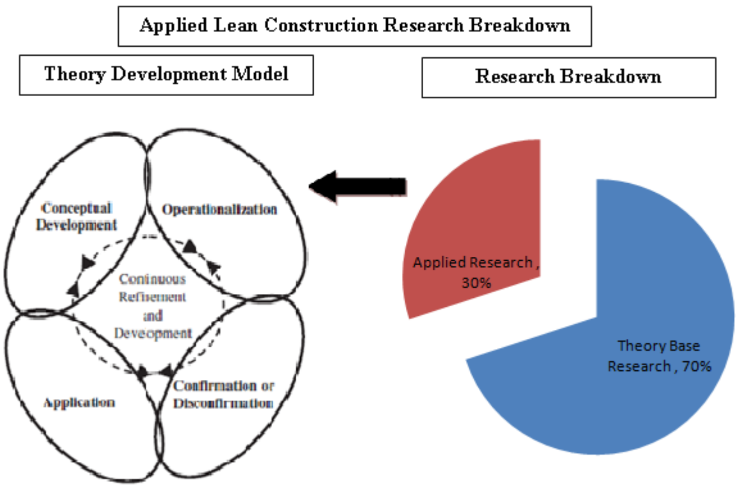


Figure 61. Applied Lean Construction Research Breakdown. Illustration of lean research and its contribution to Operationalization within the Theory Development Model.

In the context of IGLC lean research studies, the Operationalization phase within the Theory Development Model is an essential connection between the Conceptualization phase and practice. It is during this phase that theory gets tested in a real world context. IGLC research studies contributed 30% to this phase, which from the researcher's perspective shows a lack of applied research representation in lean construction research. This finding reveals a misbalance between theory and applied based research in construction. Lean research should be operationalized as opposed to remaining purely conceptual.

Implications for Action

The findings of this study have particular implications in knowledge, practice and teaching as will be delineated below.

Knowledge

The vision of IGLC was stated in Chapter Two as follows: "To better meet customer demands and dramatically improve the Architect, Engineering and Construction (AEC) process as well as product" (IGLC Portal, 2010). This vision speaks to the need for lean research in construction, which in the past was predominantly supported by researchers from academic institutions. It was not the intent of this researcher to criticize contributed lean research in construction; in actuality, progress towards lean in construction has occurred over the last 14 years. Rather, the focus of this study was to evaluate lean research studies in relation to the TPS framework. Therefore, the purpose of this study was to foster awareness among lean researchers on the current lean research platform in construction.

The study revealed an overemphasis on the TPS category of Process with 71% research representation over 14 years. The TPS framework is constructed of four prominent research categories responsible for substantial production outcomes at Toyota and in other similar manufacturing sectors. It is the researcher's belief that a similar philosophy should direct research towards a well developed lean platform in construction. The IGLC can direct research initiatives among academics and practitioners through invitation of specific research concentrations during their conferences to be more inclusive of less represented TPS categories. Therefore, the study contributed to the body of knowledge through emphasis of lean research agendas as it relates to construction. The researcher believes that this study will add value to future lean construction research because it will inform a more balanced lean research platform.

Practice

The construction sector is divided into three major segments: the building segment, heavy, and civil engineering segment. A growth rate of 19% within these sectors over the next decade is anticipated (Bureau of Labor Statistics, 2010). Such a promising industry forecast will allow the construction sector to seek better production venues for greater profit outcomes. The researcher supports the belief that a commercially vested research agenda in construction can alter lean research initiatives based on findings in the study that a majority of case studies were commissioned by construction companies, which calls into question the impartiality of the results. The researcher believes the construction sector should serve as a neutral conduit for lean research, without undue influence on the results by the commissioning companies. Quality research should stand neutral, reporting on both negative as well as positive outcomes. The researcher further supports the notion that the three construction sectors, building, heavy, and civil engineering, are different as far as their operating platforms. Therefore lean researchers should not confine their research to a one of these specific sector platforms but rather conform to a broader applied lean platform. The researcher believes that this study will contribute to the improvement of construction practices through informing industry leaders, practitioners, and consultants, based on the call for a neutral lean research platform in construction.

Teaching

Students, faculty, and practitioners in the classroom setting are direct consumers of research. A benefit of this study is to inform these consumers by emphasizing that lean is an integrated dynamic of management, process, and theory. This study distills previous lean research studies into an understanding of a balanced research platform in lean construction. This awareness will help provide students who enter the workforce with a better understanding of these integrated dynamics as applied to lean in construction.

Recommendations for Future Research

The essence of this study centered on the importance of a sound lean research platform in relation to the TPS framework in construction. A non-alignment was revealed between lean research in construction and the TPS framework. This should not diminish the value of the TPS framework and its principles to the construction operating platform. Therefore future research should strive to validate the importance of the less represented TPS categories, as well as encompassing broader research categories in lean construction. Figure 62 presents the TPS categories least represented—Philosophy, Problem Solving, and People and Partners—on a weighted scale versus strong research representation in Process.

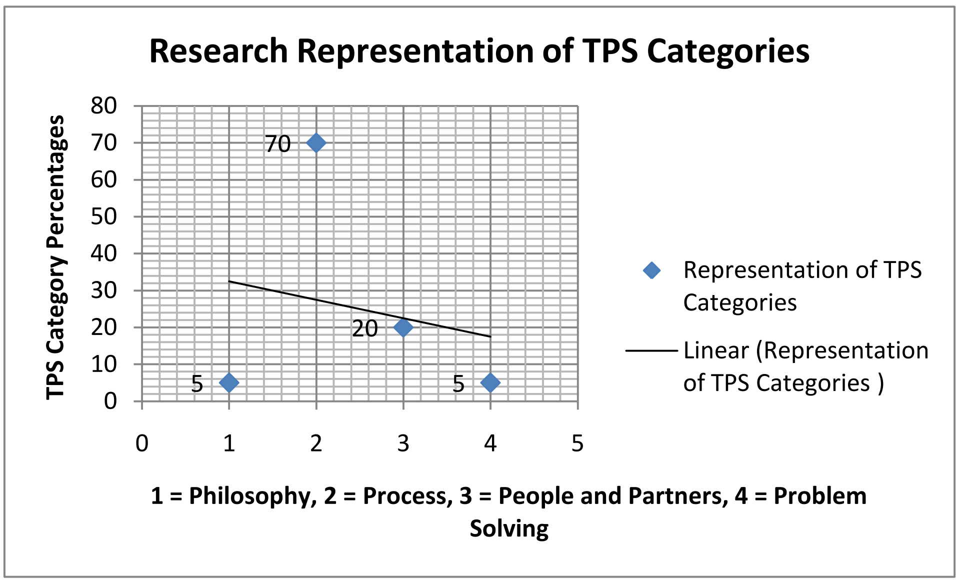


Figure62. Research representation of TPS categories. Less represented TPS categories are indicated below the line.

In connection to recommendations for future research, the researcher further advises that the sound methodology used in this study be utilized to conduct a similar study by analyzing a different lean research database.

Concluding Remarks

The researcher worked in the construction sector for 12 years where the many struggles in the industry were experienced firsthand. Similar production challenges seemed to be a common phenomenon across companies in the industry. This researcher worked in the Insurance

Restoration branch of the construction industry, which is solely funded by major insurance companies based on residential and commercial property claims. The last company the researcher worked for was an international construction franchise organization. Franchise organizations function on well-developed operating models used throughout their operating outlets. Constant refinement for improved operations in the franchise culture is standard operating procedure, where improvement measures become an implemented mantra throughout all company offices. The Operationalization phase—as explained in Lynham's (2002) Research and Theory Development Model—as shown in Figure 14, largely contributes to the successful refinement of day-to-day operations in the franchise field. Better application of the Research and Theory Development Model in construction lean research will encourage awareness of applied research in the field as was presented in Figure 61.

Research is intended to solve a particular or existing problem. It is vital to our everyday decision-making and contributes to the success or failure of change as it applies in a specific field like construction. Therefore, the success of a project or endeavor greatly lies in good research, which this study intended to emphasize through fostering awareness of lean research studies aligned against the TPS framework. The TPS framework has been shown to be an excellent model in manufacturing. Based on the results of this study, the TPS framework in construction has not been fully represented in research. Lean construction research has surpassed confinement to the TPS framework as was illustrated by the need for the 15 proxy categories created for this study. The construction industry embarked on a lean related research agenda uniquely applicable to its operating platform. This researcher encourages further exploration and implementation of the TPS principles to the construction operating platform, as well as the topics gathered in the proxy categories. Therefore, this study fostered awareness of lean research in construction by determining how accurately past IGLC studies aligned to the TPS theoretical framework, as a measure towards a sound platform of lean research in construction.

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APPENDIX A

Intrarater Reliability

Summary of Intrarater Reliability Testing

Year	Title	Author	Notes on Disagreement
2009	WORKING THROUGH UNFORSEEN UNCERTAINITES USING THE OODA LOOP: AN APPROACH FOR SELF-MANAGED CONSTRUCTION TEAMS	T.S. Abdelhamid[1], Don Schafer[2], Tim Mrozowski[3], Jayaraman, V. [4], Howell, G. [5] and Mohamed A. El-Gafy[6]	(Correct) Models & Feedback
2009	LAST PLANNER SYSTEM: EXPERIENCES FROM PILOT IMPLEMENTATION IN THE MIDDLE EAST	Abdullah AlSehaimi1, Patricia Tzortzopoulos2 and Lauri Koskela3	(Correct) Models & Feedback
2009	INCENTIVES AND INNOVATION TO SUSTAIN LEAN CONSTRUCTION IMPLEMENTATION	Thaís da C. L. Alves[1], José de P. Barros Neto [2], Luis F. M. Heineck[3], Sergio L. Kemmer[4] and Pedro E. Pereira[5]	Was originally classified under Models and Feedback (Interrater classified it under Process)
2009	ERGONOMIC EXPOSURES FROM THE USAGE OF CONVENTIONAL AND SELF COMPACTING CONCRETE	Peter Simonsson1 and Romuald Rwamamara2	(Correct) Outside Lean Framework
2009	SETPLAN: A COMPUTER TOOL TO AID IN SET-BASED DESIGN	John-Michael Wong[1], Kristen Parrish[2], Iris D. Tommelein[3] and Bozidar Stojadinovic[4]	(Correct) Theory
2008	USING REAL OPTION VALUATION THEORY TO MEASURE BENEFITS FROM UNCERTAIN COSTS REDUCTIONS	Carlos Alexandre C. de Abreu[1] and J.P. Barros Neto[2]	(Correct) Finance Cost
2008	WHAT CAN BE LEARNED FROM STUDIES ON DELAY IN CONSTRUCTION?	Abdullah AlSehaimi [1] and Lauri Koskela[2]	(Correct) Outside Lean Framework

2008	APPROACHING CONSTRUCTION AS A LOGISTICAL, ECONOMICAL AND SOCIAL PROCESS	Bjørn Andersen[1], Trond Bølviken[2], Hege Skårbekk Dammerud[3] and Sol Skinnarland[4]	(Correct) Outside Lean Framework
2008	FROM PERFORMANCE TARGETS TO SERVICE DESIGN AND HEALTHCARE INFRASTRUCTURE	Therese Lawlor-Wright[1], Patricia Tzortzopoulos[2], Ricardo Codinhoto[3], Mike Kagioglou[4] and Lauri Koskela[5]	(Correct) Outside Lean Framework
2008	CASE STUDY: LEAN SUPPLY CHAIN MANAGEMENT IN CONSTRUCTION PROJECTS	Eric Zimmer[1], Ossama Salem[2],AshrafGenaidy[3] and Richard Shell[4]	(Correct) Supply Chain
2007	THE TFV THEORY OF PRODUCTION: NEW DEVELOPMENTS	Lauri Koskela[1], John Rooke[2], Sven Bertelsen[3], Guilherme Henrich[4]	(Correct) Theory
2007	CONSTRUCTION PHYSICS	Sven Bertelsen[1], Guilherme Henrich[2], Lauri Koskela[3] and John Rooke[4]	(Correct) Theory
2007	THE METHOD OF ANALYSIS IN PRODUCTION MANAGEMENT	Ricardo Codinhoto[1], Lauri Koskela[2], Patricia Tzortzopoulos[3], and Mike Kagioglou[4]	(Correct) Theory
2007	TOWARDS A NEW UNDERSTANDING OF THE CONSTRUCTION INDUSTRY AND THE NATURE OF ITS PRODUCTION	Sven Bertelsen[1] and Rafael Sacks[2]	(Correct) Theory
2007	INTERFACE MANAGEMENT—A FACILITATOR OF LEAN CONSTRUCTION AND AGILE PROJECT MANAGEMENT	Qian Chen[1], Georg Reichard[2] and Yvan Beliveau[3]	(Correct) Theory

2006	AN ON-SITE MATERIAL HANDLING CALCULATION MODEL	Basil Al-Sasi[1] and David C. Brown[2]	(Correct) Logistics
2006	SIMULATION AS A TOOL FOR PRODUCTION SYSTEM DESIGN IN CONSTRUCTION	Thais da C. L. Alves[1], Iris D. Tommelein[2] and Glenn Ballard[3]	(Correct) Models & Feedback
2006	INVESTIGATION OF BUFFER DYNAMICS IN SHEET METAL DUCTWORK SUPPLY CHAINS	Thais da C. L. Alves[1] and Iris D. Tommelein[2]	(Correct) Models & Feedback
2006	A DESIGN CASE STUDY: INTEGRATED PRODUCT AND PROCESS MANAGEMENT	Roberto Arbulu[1] and Javier Soto[2]	(Correct) Design Management
2006	IMPLEMENTING LEAN IN CONSTRUCTION: HOW TO SUCCEED	Roberto Arbulu[1] and Todd Zabelle[2]	(Correct) Philosophy
2005	AN ON-SITE MATERIAL HANDLING CALCULATION MODEL	Basil Al-Sasi[1] and David C. Brown[2]	(Correct) Process
2005	SIMULATION AS A TOOL FOR PRODUCTION SYSTEM DESIGN IN CONSTRUCTION	Thais da C. L. Alves[1], Iris D. Tommelein[2] and Glenn Ballard[3]	(Correct) Process
2004	MANUFACTURING HOUSING CONSTRUCTION VALUE USING ANALITICAL HIERARGHY PROCESS	Afshan Barshani[1], Tariq S. Abdelhamid[2], and Matt Syal[3]	(Correct) Outside Lean Framework
2004	SELFDESTRUCTION AND RENEWAL OF CONSTRUCTION THEORY	Tariq S. Abdelhamid[1]	(Correct) Theory
2003	SIGNAL DETECTION THEORY	Abdelhamid, T.S.[1], Patel, B. [2], Howell, G.A.[3], and Mitropoulos, P	(Correct) Safety
2003	SIX-SIGMA IN LEAN CONSTRUCTION SYSTEMS	TARIQ S. ABDELHAMID[1]	(Correct) Literature Review

2002	PHYSICAL DEMANDS OF CONSTRUCTION WORK: A SOURCE OF WORKFLOW UNRELIABILITY	Tariq S. Abdelhamid[1] and John G. Everett[2]	(Correct) People Partners
2002	COLLABORATIVE IMPLEMENTATION OF LEAN PLANNING SYSTEMS IN CHILEAN CONSTRUCTION COMPANIES	Luis F. Alarcón[1], Sven Diethelmand[2] and Oscar Rojo[3]	(Correct) Process
2001	INTEGRATING SAFETY INTO PRODUCTION PLANNING AND CONTROL PROCESS: AN EXPLORATORY STUDY	Tarcisio Abreu Saurin, Carlos Torres Formoso , and Lia Buarque de Macedo Guimarães [3]	(Correct) Safety
2000	ACHIEVING A LEAN DESIGN PROCESS	Javier Freire1 and Luis F. Alarcón	(Correct) Design Management
2000	INTERPLAY OF PROJECT COMPLEXITY AND LEAN PRODUCTION METHODS	Abdulsalam A. Al-Sudairi1, James E. Diekmann2 and Anthony D. Songer	(Correct) Process

Intrarater Reliability (96%) 29 out of 30 research studies.

APPENDIX B

Interrater Reliability Summary

Year	Title	Author	Notes on Disagreement
1996	PERFORMANCE MEASURING BENCHMARKING, AND MODELLING OF CONSTRUCTION PROJECTS	Luis F. Alarcón and Alfredo Serpell	
1996	PARTNERING, LEAN PRODUCTION AND THE HGIHT PERFORMANCE WORKPLACE	James Barlow	
1996	THE APPLICATION OF LEAN PRODUCTION TO PROJECT MANAGEMENT	Michael Horman & Russell Kenley	
1996	TOWARDS THE THEORY OF (LEAN) CONSTRUCTION	Lauri Koskela	
1996	LEAN CONSTRCUTION THEORY AS AN EXERCISE IN PRACTICAL REASONING	John Rooke & Darryll Crook	
1996	A GENERAL FRAMEWORK FOR IMPROVEMENT OF THE CONSTRUCTION PROCESS	Alfredo Serpell, Luis Fernando Alarcón and Virgilio Ghio	
1997	LOOKAHEAD PLANNING: THE MISSING LINK IN PRODUCTION CONTROL	Glenn Ballard	
1997	DOING LEAN CONSTRUCTION AND TALKING ABOUT LEAN CONSTRUCTION	David Seymour,John Rooke,Darryll Crook	
1997	PROCESS IMPROVEMENT OF THE BUILDING SERVICES ENGINEERING INDUSTRY: THE TRANSATLANTIC CHALLENGE	Charles Fowler	
1997	PREPLANNING: A REWARDING EXPERIENCE	Virgilio A. Ghio, Ernesto Valle, Leonardo Rischmoller	
1997	DISCRETE-EVENT SIMULATION OF LEAN CONSTRUCTION PROCESSES	Iris D. Tommelein	
1997	TOWARDS LEAN DESIGN MANAGEMENT	Lauri Koskela, Glenn Ballard, Veli-Pekka Tanhuanpää	
1998	PROACTIVE APPROACH FOR REDUCING NON-VALUE ADDING ACTIVITIES DUE TO TIME-SPACE CONFLICTS	Burcu Akinci1, Martin Fischer2, and Todd Zabelle	
1998	UNRAVELLING THE VALUE	Brian Atkin	

	CHAIN IN CONSTRUCTION	
1998	FROM CRAFT PRODUCTION TO MASS CUSTOMISATION? CUSTOMER-FOCUSED APPROACHES TO HOUSEBUILDING	James Barlow
1998	DEVELOPING A MODEL FOR PLANNING AND CONTROLLING PRODUCITON IN SMALL SIZE BUILDING FIRMS	Carlos T. Formoso1, Maurício Bernardes2, and Luiz Fernando Oliveira
1998	PLANNING AND CONTROLLING PRODUCTION IMPLEMENTING LEAN CONSTRUCTION: UNDERSTANDING AND ACTION	Greg Howell1 and Glenn Ballard
1998	LAST PLANNER AS A SITE OPERATIONS TOOL	João Auada Junior1, Alexandre Scola1, and Antonio Sergio Itri Conte
1999	PLAYING GAMES: EVALUATING THE IMPACT OF LEAN PRODUCTION STRATEGIES ON PROJECT COST AND SCHEDULE	Luis F. Alarcón1 and David B. Ashley
1999	ENTREPRENEURIAL STRATEGIES AND NEW FORMS OF RATIONALISATION OF PRODUCTION IN THE BUILDING CONSTRUCTION SECTOR OF BRAZIL AND FRANCE	Francisco F. Cardoso
1999	METHOD FOR WASTE CONTROL IN THE BUILDING INDUSTRY	Carlos Torres Formoso1, Eduardo Luís Isatto2, and Ercilia Hitomi Hirota
1999	WHAT IS LEAN CONSTRUCTION - 1999	Gregory A. Howell
1999	DEVELOPING LEAN AND AGILE SUPPLY CHAINS IN THE UK HOUSBUILDING INDUSTRY	M. Naim1, J. Naylor2, and J. Barlow3
1999	HIGH-TURNAROUND AND FLEXIBILITY IN DESIGN AND CONSTRUCTION OF MASS HOUSING	Amarjit Singh1, Rick Barnes2, and Ali Yousefpour
2000	ACHIEVING A LEAN DESIGN PROCESS	Javier Freire1 and Luis F. Alarcón

2000	HOUSE BUILDING SUPPLY CHAIN STRATEGIES	Paul Childerhouse1, Séverine M. Hong-Minh2 and, Mohamed M. Naim
2000	A NON-DETERMINISTIC INVESTIGATION OF THE CONCRETE PLACING SYSTEM	Paul Dunlop1, Simon Smith
2000	REFORMING PROJECT MANAGEMENT: THE ROLE OF LEAN CONSTRUCTION	Gregory A. Howell, P.E. 1 and Lauri Koskela, Dr.Tech
2000	Construction process models – enabling a shared project understanding	Roine Leiringer1
2000	REDUCTION OF WORK-IN-PROGRESS IN THE CONSTRUCTION ENVIRONMENT	SANTOS, Aguinaldo1, POWELL, James Andrew2, SARSHAR, Marjan
2001	Considerations for Streamlining	Nadia G. Akel1, Iris D. Tommelein2, J.C. Boyers3, Kenneth D. Walsh4, and James C. Hershauer5
2001	CONSTRAINT MODELING AND BUFFER MANAGEMENT WITH INTEGRATED PRODUCTION SCHEDULER	David, K. H. Chua1 , and Li Jun Shen
2001	Envelopment Methodology to Measure and Compare Subcontractor Productivity at the Firm Level	Mohammad El-Mashaleh1, William J. O'Brien2, Kerry London3
2001	CAPACITY UTILIZATION AND WAIT TIME: A PRIMER FOR CONSTRUCTION	Gregory A. Howell1, Glenn Ballard2, and Jerome Hall3
2001	PERFORMANCE IMPROVEMENT PROGRAMS AND LEAN CONSTRUCTION	Panagiotis (Takis) Mitropoulos1 and Gregory Howell2

2002	PHYSICAL DEMANDS OF CONSTRUCTION WORK: A SOURCE OF WORKFLOW UNRELIABILITY	Tariq S. Abdelhamid1 and John G. Everett2
2002	CONTRIBUTIONS TO THE EVALUATION OF PRODUCTION PLANNING AND CONTROL SYSTEMS IN BUILDING COMPANIES	Maurício M. S. Bernardes1 and Carlos T. Formoso2
2002	CAN KNOW-HOW BE SIGNALED?	Nuno Gil1
2002	PREFABRICATION FOR LEAN BUILDING SERVICES DISTRIBUTION	M. J. Mawdesley1 and G. Long2
2002	SAFETY AND PRODUCTION: AN INTEGRATED PLANNING AND CONTROL MODEL	Tarcisio A. Saurin1, Carlos T. Formoso2, Lia B. M. Guimarães3 and Alexandre C. Soares4
2003	SIGNAL DETECTION THEORY	Abdelhamid, T.S.1, Patel, B. 2, Howell, G.A.3, and Mitropoulos, P
2003	CONSTRUCTION AS A COMPLEX SYSTEM	Sven Bertelsen1
2003	NON VALUE-ADDING ACTIVITIES IN BUILDING PROJECTS: A PRELIMINARY CATEGORIZATION	Per-Erik Josephson1, Lasse Saukkoriipi2
2003	ALIGNING THE LEAN ORGANIZATION: A CONTRACTUAL APPROACH	Owen Matthews1, Gregory A. Howell2 & Panagiotis Mitropoulos3
2003	INCREASING THE UNDERSTANDING OF LEAN PRINCIPLES WITH ADVANCED VISUALIZATION TECHNOLOGIES	Bo Tan1, Michael J. Horman2, John I. Messner3, and David R. Riley4
2004	MANUFACTURING HOUSING CONSTRUCTION VALUE USING ANALITICAL HIERARGHY PROCESS	Afshan Barshani[1], Tariq S. Abdelhamid[2], and Matt Syal[3]
2004	SYSTEM FOR EVALUATING ONGOING BUILDING PROCESS	Randi Muff Ebbesen[1]

2004	REVEALING CULTURES AND SUB-CULTURES DURING IMPLEMENTATION OF LEAN CONSTRUCTION	Bo Jorgensen!, Stephen Emmitt2, and Sten Bonke[3]
2004	THEORY OF WORKPLACE PLANNING - GENERAL PRINCIPLES AND MANAGEMENT STEERING MODEL	Ari Pennanent, Michael Whelton[2] & Glenn Ballard[3]
2004	SHAPING LEAN CONTRUCTION IN PROJECT BASED ORGANISATIONS	Rolf Simonsen! and Christian Koch2
2005	ON THE METAPHYSICS OF PRODUCTION	Lauri Koskela1 and Mike Kagioglou2
2005	CASE STUDY OF THE IMPLEMENTATION OF THE LEAN PROJECT DELIVERY SYSTEM (LPDS) USING VIRTUAL BUILDING TECHNOLOGIES ON A LARGE HEALTHCARE PROJECT	Atul Khanzode1, Martin Fischer2 and Dean Reed
2005	PRODUCT DESIGN FOR IMPROVED MATERIAL FLOW—A MULTI-STOREY TIMBER HOUSING PROJECT	Anders Björnfot1 and Lars Stehn
2005	EFFECTIVENESS OF LEAN PRINCIPLES IN CONSTRUCTION	Satish B. Mohan1 and Sumathi Iyer2
2005	LEAN PRINCIPLES FOR PREFABRICATION IN GREEN Design Build	Yupeng Luo1, David R. Riley2 and Michael J. Horman3
2006	AN ON-SITE MATERIAL HANDLING CALCULATION MODEL	Basil Al-Sasi1 and David C. Brown2
2006	RETHINKING PROJECT DEFINITION IN TERMS OF TARGET COSTING	Glenn Ballard1
2006	HOW ANALYSIS AND SYNTHESIS HAVE BEEN UNDERSTOOD IN DESIGN	Ricardo Codinhoto1, Lauri Koskela2, Patricia Tzortzopoulos3, Mike Kagioglou4
2006	CUSTOMER VALUE IN LEAN PREFABRICATION OF HOUSING CONSIDERING BOTH CONSTRUCTION AND MANUFACTURING	Matilda Höök1

2006	IS AGILE PROJECT MANAGEMENT APPLICABLE TO CONSTRUCTION?	Robert Owen1, Lauri Koskela2, Guilherme Henrich3 and Ricardo Codinhoto4
2007	THE TFV THEORY OF PRODUCTION: NEW DEVELOPMENTS	Lauri Koskela1, John Rooke2, Sven Bertelsen3, Guilherme Henrich4
2007	A SUBCONTRACTOR'S LEAN JOURNEY: A CASE STUDY ON ILYANG	Yong-Woo Kim1, Jin Woo Jang2, and Glenn Ballard3
2007	GREEN BUILDING RATING AND DELIVERY SYSTEMS IN BUILDING CONSTRUCTION: TOWARD AEC+P+F INTEGRATION	Karthik Ramkrishnan[1], Kathy Roper[2] and Daniel Castro-Lacouture[3]
2007	EXPLORATION OF SET-BASED DESIGN FOR REINFORCED CONCRETE STRUCTURES	Kristen Parrish1, John-Michael Wong2, Iris D. Tommelein3, and Bozidar Stojadinovic4
2007	APPLICATION OF THE PRINCIPLE OF BATCH SIZE REDUCTION IN CONSTRUCTION	Steven. A. Ward1 and Andrew McElwee2

Interrater: Andrea K. Greenwall Shreve, M. Ed., with a Minor in Construction Management

APPENDIX C

OUTSIDE LEAN FRAMWORK RESEARCH STUDIES

2002	TOWARDS THE DEVELOPMENT OF A CONCEPTUAL DESIGN MANAGEMENT MODEL FOR REMOTE SITES	Linda Kestle [1] and Kerry London
2003	AN INTERNATIONAL COMPARISON OF THE DELIVERY PROCESS OF POWER DISTRIBUTION EQUIPMENT	Jan A. Elfving[1], Iris D. Tommelein[2], Glenn Ballard[3]
2003	ASSESSING DESIGN PRACTICES ON AFFORDABLE HOUSING PROJECTS IN MEXICO USING LEAN CONCEPTS	José H. Loría-Arcila[1], Alcides García-García[2] and Jorge A. Vanegas[3]
2003	APPLICATION OF TOLERANCE ANALYSIS AND ALLOCATION IN WORK STRUCTURING: PARTITION WALL CASE	Colin Milberg[1] and Iris D. Tommelein
2003	VALUE OF VISIBILITY AND PLANNING IN AN ENGINEER-TO-ORDER ENVIRONMENT	Kalyan Vaidyanathan[1]
2004	NON-UNIT BASED PLANNING AND SCEDULING OF REPETITIVE CONSTRUCTION PROJECTS	Rong-yau Huang! and Kuo-Shun Sun[2]
2004	CUSTOMER SATISFACTION IN CONSTRUCTION	Sami KarnaI, Juha-Matti Junnonen[2], and Jouko Kankainen[3]
2004	QUALITY CONTROL IN LEAN CONSTRUCTION	Esben Misfelde and Sten Bonke[2]
2004	TOYOTA PRODUCTION SYSTEM ADOPTED BY BUILDING CONSTRUCTION IN JAPAN	Yoshitaka Nakagawa and Yoshitugu Shimizu[2]
2004	ACTIVATION OF HIDDEN RESOURCES EXPERIENCE FROM DEVELOPMENT INITIATIVE IN REGIONAL AREA IN DENMARK	Willy Olsen!, Randi Muff Ebbesen[2], Soren Wandahe and Erik Bejder[4]
2004	OFF SITE PRODUCTION - EVALUATING DRIVERS AND CONSTRAINTS	Christine Pasquire 1Alistair Gibb2 Nick Blismas3
2004	THEORY OF WORKPLACE PLANNING - GENERAL PRINCIPLES AND MANAGEMENT STEERING MODEL	Ari Pennanent, Michael Whelton[2] & Glenn Ballard[3]

2004	FOSTERING COLLABORATION AND LEARNING LEARNING IN PROJECT DEFINITION	Michael Whelton!, Ari Pennanen[2] & Glenn Ballard[3]
2004	TOLORANCE MAPPING - PARTITION WALL CASE REVISITED	Colin Milberg! and Iris D. Tommelein[2]
2004	PERSPECTIVES ON NON-VALUE ADDED ACTIVITIES - CASE OF PIECE RATE IN SWEDISH CONSTRUCTION	Lasse Saukkoriipi[1]
2004	SHAPING LEAN CONTRUCTION IN PROJECT BASED ORGANISATIONS	Rolf Simonsen! and Christian Koch2
2005	MODULARIZATION—A THIRD APPROACH TO MAKING CONSTRUCTION LEAN?	Sven Bertelsen1
2005	RETURN ON INVESTMENT IN CONSTRUCTION INNOVATION—A LEAN CONSTRUCTION CASE STUDY	Andre Koerckel1 and Glenn Ballard
2005	EVALUATION OF A GPS SUPPORT SYSTEM FOR FLEET	Peter Simonsson1 and Jonas Carlswärd
2005	PRODUCT DESIGN FOR IMPROVED MATERIAL FLOW—A MULTI-STOREY TIMBER HOUSING PROJECT	Anders Björnfot1 and Lars Stehn
2005	CONNECTING LEAN CONSTRUCTION TO PREFABRICATION COMPLEXITY IN SWEDISH VOLUME ELEMENT HOUSING	Matilda Höök1 and Lars Stehn
2005	THEORY & PRACTICE OF MODULAR COORDINATION	Alan. J. Brookes
2005	OPPORTUNITIES FOR CLIENT REQUIREMENTS MANAGEMENT IN LOW-INCOME HOUSE BUILDING PROJECTS IN BRAZIL	Fernanda Lustosa Leite1, Luciana Inês Gomes Miron2 and Carlos Torres Formoso
2005	ASSESSING THE IMPACTS OF IMPLEMENTING LEAN	Luis F. Alarcón1, Sven Diethelm2, Oscar Rojo3 and Rodrigo Calderon
2005	DIVERGENT FOCUS IN THE APPLICATION OF LEAN IDEAS: EXAMPLES FROM DENMARK AND CALIFORNIA	Bo Jørgensen1, Stephen Emmitt2 and Glenn Ballard3
2005	CASE STUDY: AN APPLICATION OF LAST PLANNER TO HEAVY CIVIL CONSTRUCTION IN KOREA	Yong-Woo Kim1 and Jin-Woo Jang2

2005	A QUANTITATIVE ANALYSIS OF THE IMPLEMENTATION OF THE LAST PLANNER SYSTEM IN BRAZIL	Rodrigo Cremonesi Bortolazza1, Dayana Bastos Costa2 and Carlos Torres Formoso
2005	EFFECTIVENESS OF LEAN PRINCIPLES IN CONSTRUCTION	Satish B. Mohan1 and Sumathi Iyer2
2005	LEAN PRINCIPLES TO INJECT OPERATIONS KNOWLEDGE INTO DESIGN	Peter K. Dahl1, Michael J. Horman2 and David R. Riley
2005	COMPARISON OF THE ECONOMICS OF ON-SITE AND OFF-SITE FABRICATION OF REBAR IN TURKEY	Gul Polat1 and Glenn Ballard2
2005	WHY IS ON-SITE FABRICATION OF CUT & BENT REBAR PREFERRED IN TURKEY?	Gul Polat1 and Glenn Ballard2
2005	OPEN BUILDING/ LEAN CONSTRUCTION EVALUATION OF A CASE IN BRAZIL	Ype Cuperus1 and Paulo Napolitano2
2005	INDUSTRIALISED HOUSING: DEFINITION AND CATEGORIZATION OF THE CONCEPT	Jerker Lessing1, Lars Stehn2, and Anders Ekholm3
2005	WHAT SHOULD YOU REALLY MEASURE IF YOU WANT TO COMPARE PREFABRICATION WITH TRADITIONAL CONSTRUCTION	Christine Pasquire1, Alistair Gibb2 and Nick Blismas
2005	AN APPLICATION OF ARTIFICIAL INTELLIGENCE PLANNER FOR BESPOKE PRECAST CONCRETE PRODUCTION PLANNING	Vacharapoom Benjaoran1 and Nashwan Dawood
2005	IMPROVING WORK FLOW RELIABILITY THROUGH QUALITY CONTROL MECHANISMS	Marton Marosszeky1, Khalid Karim2, Salinda Perera3 and Steve Davis
2005	CULTURE OF QUALITY AND THE AUSTRALIAN CONSTRUCTION INDUSTRY	Swapan Saha1 and Mary Hardie
2005	LEAN PRINCIPLES FOR PREFABRICATION IN GREEN Design Build	Yupeng Luo1, David R. Riley2 and Michael J. Horman3
2006	RETHINKING PROJECT DEFINITION IN TERMS OF TARGET COSTING	Glenn Ballard[1]
2006	SUBCONTRACTOR RESOURCE ALLOCATION IN A MULTI-PROJECT ENVIRONMENT – FIELD STUDY	Michael Harel[1] and Rafael Sacks[2]

2006	BEYOND PRE-FABRICATION - THE POTENTIAL OF NEXT GENERATION TECHNOLOGIES TO MAKE A STEP CHANGE IN CONSTRUCTION MANUFACTURING	Christine Pasquire[1], Rupert Soar[2], Alistair Gibb[3]
2006	HOW TO PROMOTE OFF-SITE FABRICATION PRACTICE OF REBAR IN TURKEY?	Gul Polat[1] and Glenn Ballard[2]
2006	PROCESS BENEFITS FROM USE OF STANDARD PRODUCTS – SIMULATION EXPERIMENTS USING THE PIPE SPOOL MODEL	Iris D. Tommelein[1]
2006	A BETTER PLAN FOR CONSTRUCTION COMPANIES	Vilma Villarouco[1], Andréa Fittipaldi[2]
2007	LEAN CONSTRUCTION TRIAL ON A HIGHWAYS MAINTENANCE PROJECT	Mary Ansell[1], Mike Holmes[2], Rees Evans[3], Christine Pasquire [4] and Andrew Price[5]
2007	A CASE STUDY ON REBAR SUPPLY CHAIN MANAGEMENT BY GS E&C	Yong-Woo Kim[1], Chanjung Park[2], and Glenn Ballard[3]
2007	A SUBCONTRACTOR'S LEAN JOURNEY: A CASE STUDY ON ILYANG	Yong-Woo Kim[1], Jin Woo Jang[2], and Glenn Ballard[3]
2007	CONSTRUCTION SUPPLY CHAIN MATURITY MODEL – CONCEPTUAL FRAMEWORK	Kalyan Vaidyanathan[1] and Gregory Howell[2]
2007	INTEGRATED STEEL DESIGN: APPLYING LEAN CONCEPTS	C. Ben Farrow[1]
2007	DO PROJECTS HAVE HORSEMEN?: INVESTIGATING THE WARNING SIGNS OF UNRELIABLE COMMITMENTS	James Folkestad[1], Gregory Howell[2]
2007	GREEN BUILDING RATING AND DELIVERY SYSTEMS IN BUILDING CONSTRUCTION: TOWARD AEC+P+F INTEGRATION	Fritz Gehbauer[1], Gert Zülch[2], Ott, Michael [3], Mikko Börkircher[4]
2007	ASSESSING THE EFFECTS OF STRUCTURAL DIFFERENCES ON ACTION, REACTION AND CONFORMATION IN CONSTRUCTION PROJECTS	Antonio N. de Miranda Filho[1], Jorge Moreira da Costa[2] and Luiz F. M. Heineck[3]

2007	QUANTIFYING THE BENEFITS OF USING E-MARKETPLACE IN CONSTRUCTION COMPANIES	Ignacio Schonherr[1], Luis F. Alarcón[2] and Sergio Maturana[3]
2007	USING VISUAL INTERACTIVE SIMULATION TO IMPROVE DECISION-MAKING IN PRODUCTION SYSTEM DESIGN	Fabio K. Schramm[1] and Carlos T. Formoso[2]
2007	IMPLICATIONS OF ACTION THEORIES TO LEAN CONSTRUCTION APPLICATIONS	Bolivar A. Senior[1]
2007	IMPROVED TEMPORARY CONSTRUCTION LIGHTING AS A METHOD OF IMPROVING PRODUCTIVITY AND QUALITY	Bruce W. Smith, CPC[1] and C. Ben Farrow[2]
2007	UNDERSTANDING LABOUR PRODUCTIVITY AS AN EMERGENT PROPERTY OF INDIVIDUAL AND CREW INTERACTIONS ON A CONSTRUCTION SITE	Matt Watkins[1], Amlan Mukherjee[2], Nilufer Onder[3] and Kris G. Mattila[4]
2008	WHAT CAN BE LEARNED FROM STUDIES ON DELAY IN CONSTRUCTION?	Abdullah AlSehaimi [1] and Lauri Koskela[2]
2008	APPROACHING CONSTRUCTION AS A LOGISTICAL, ECONOMICAL AND SOCIAL PROCESS	Bjørn Andersen[1], Trond Bølviken[2] , Hege Skårbekk Dammerud[3] and Sol Skinnarland[4]
2008	LAST PLANNER IN A SOCIAL PERSPECTIVE – A SHIPBUILDING CASE	Sigmund Aslesen[1] and Sven Bertelsen[2]
2008	ASSESSING THE ENVIRONMENTAL IMPACTS OF LEAN SUPPLY SYSTEM: A CASE STUDY OF HIGH-RISE CONDOMINIUM CONSTRUCTION IN SEOUL, KOREA	Jin-Woo Bae[1] and Yong-Woo Kim[2]
2008	IMPROVEMENT OF PERFORMANCE MEASUREMENT SYSTEMS USING PRODUCTION MANAGEMENT DASHBOARDS	Karina B. Barth[1] and Carlos T. Formoso[2]
2008	ON-SITE 3D VISION TRACKING OF CONSTRUCTION PERSONNEL	Francisco Cordova[1] and Ioannis Brilakis[2]
2008	A CRITICAL LOOK AT INTEGRATING PEOPLE, PROCESS AND INFORMATION SYSTEMS WITHIN THE CONSTRUCTION SECTOR	Bhargav Dave[1], Lauri Koskela[2], Mike Kagioglou[3] and Sven Bertelsen[4]

2008	STATE-OF-THE-ART SHIPBUILDING: TOWARDS UNIQUE AND INTEGRATED LEAN PRODUCTION SYSTEMS	Karolis Dugnas[1] and Oddmund Oterhals[2]
2008	MODELING THE EFFECT OF REWORK TIMING: CASE STUDY OF A MECHANICAL CONTRACTOR	Peter P. Feng[1], Iris D. Tommelein[2] and Lawrence Booth[3]
2008	APPLICATION OF PRODUCTION MANAGEMENT IN INDUSTRIAL EPC AND MINING PROJECTS IN PERU	Jorge Luis Izquierdo[1] and Roberto Arbulu[2]
2008	ASSESSMENT OF UNCERTAINTY MANAGEMENT APPROACHES IN CONSTRUCTION ORGANIZATIONS	Venkataramanan Jayaraman[1],Tariq S. Abdelhamid[2] and Benedict D. Ilozor [3]
2008	ASSESSING PROJECT STAFFING REQUIREMENTS USING UNSUPERVISED CLUSTERING TECHNIQUES	Arthur W. T. Leung[1] and C M Tam[2]
2008	INTEGRATING INFORMATION ACROSS CONSTRUCTION SUPPLY CHAIN USING ND MODELLING	Xianguang Li[1], Ghassan Aouad[2], Peter McDermott[3], Ying Liu[4] and Carl Abbott[5]
2008	IMPROVING LABOR PRODUCTIVITY THROUGH PRODUCTION CONTROL	Min Liu[1] and Glenn Ballard[2]
2008	EXPERIENCE FEEDBACK AT INDUSTRIALISED HOUSE BUILDERS	John Meiling[1] and Helena Johnsson[2]
2008	LEAN –IN-NIGERIAN CONSTRUCTION: STATE, BARRIERS, STRATEGIES AND “GO-TOGEMBA” APPROACH	Joseph Oladiran Olatunji[1]
2008	CRAFT CONSTRUCTION, MASS CONSTRUCTION, LEAN CONSTRUCTION: LESSONS FROM THE EMPIRE STATE BUILDING	Rebecca Partouche[1], Rafael Sacks[2] and Sven Bertelsen[3]
2008	USING THE “FIVE WHYS” AS A DECISIONMAKING FRAMEWORK FOR EVIDENCEBASED DESIGN	Zofia K. Rybkowski[1] and Glenn Ballard[2]
2009	OPPORTUNITIES TO ADOPT MASS CUSTOMISATION – A CASE STUDY IN THE BRAZILIAN HOUSE BUILDING SECTOR	Patricia André Tillmann[1] and Carlos Torres Formoso[2]

2009	FROM PERFORMANCE TARGETS TO SERVICE DESIGN AND HEALTHCARE INFRASTRUCTURE	Therese Lawlor-Wright[1], Patricia Tzortzopoulos[2], Ricardo Codinhoto[3], Mike Kagioglou[4] and Lauri Koskela[5]
2009	IDENTIFYING ROOT CAUSES OF LONG REVIEW TIMES FOR ENGINEERING SHOP DRAWINGS	Chang-Sun Chin[1]
2009	WORK-IN-PROCESS AND CONSTRUCTION PROJECT INFORMATION FLOWS	Chang-Sun Chin[1]
2009	A FRAMEWORK FOR CONSTRUCTION REQUIREMENTS BASED PLANNING UTILIZING CONSTRAINTS LOGIC PROGRAMMING	David K.H. Chua[1] and K.W. Yeoh[2]
2009	AN INNOVATIVE SELF-ASSESSMENT APPROACH FOR MINIMIZATION OF CONSTRUCTION PECULARITIES ON LEAN-ORIENTED D&B PROJECTS	Christy P. Gomez1
2009	INTEGRATED MODEL OF WEIGHTING AND EVALUATING DECISION CRITERIA FOR SUPPORTING BEST-VALUE CONTRACTOR SELECTION	Chun-Chang Lin[1], Wei-Chih Wang[2] and Wen-Der Yu[3]
2009	SIMULATION-BASED SCHEDULING MODEL FOR MULTIPLE DESIGN PROJECTS	Jang-Jeng Liu[1] and Wei-Chih Wang[2]
2009	INTEGRATED SUPPLY CHAIN CONSTRUCTION ECOSYSTEM MANAGEMENT	Kim A. Maund1 and Kerry London2
2009	DECISION ANALYSIS USING VIRTUAL FIRST-RUN STUDY OF A VISCOUS DAMPING WALL SYSTEM	Hung V. Nguyen[1], Baris Lostuvali [2] and Iris D. Tommelein [3]
2009	UNDERSTANDING THE RELATIONSHIP BETWEEN PLANNING RELIABILITY AND SCHEDULE PERFORMANCE: A CASE STUDY	Ricardo M. Olano1, Luís F. Alarcón2 and Carlos Rázuri3
2009	A TWO DIMENSIONAL VIEW OF THE SUPPLY CHAIN ON CONSTRUCTION PROJECTS	Salinda Perera1, Steven Davis2 and Marton Marosszeky3
2009	ANALYSIS FRAMEWORK FOR THE INTERACTION BETWEEN LEAN CONSTRUCTION AND BUILDING INFORMATION MODELLING	Rafael Sacks[1], Bhargav A. Dave[2], Lauri Koskela[3] and Robert Owen[4]

2009	REDESIGNING THE PRODUCTION SYSTEM TO INCREASE FLEXIBILITY IN HOUSE BUILDING PROJECTS	Fábio K. Schramm[1], Patrícia A. Tillmann[2], Letícia R. Berr[3] and Carlos T. Formoso[4]
2009	ERGONOMIC EXPOSURES FROM THE USAGE OF CONVENTIONAL AND SELF COMPACTING CONCRETE	Peter Simonsson1 and Romuald Rwamamara2