Fernández-Solís, J L (2009) An Application of
Popper's Method of Conjectures and Refutations to
the Critique of Emerging Construction Theories-
Lean Construction Journal 2009 pp 37-60

An Application of Popper's Method of Conjectures and Refutations to the Critique of Emerging Construction Theories

José L. Fernández-Solís[1]

Abstract

Karl Popper's method of conjectures and refutationsis used as a framework to analyze and critique emerging construction theories. A perceived problem initiates the quest for tentative theories and error elimination as a solution. However, according to Popper, the result is a new version of the problem or an unintended consequence that creates anemergingproblem.

The method of conjectures and refutations is a novel gateway into critiquing current theories by challenging the finding of a solution that does not in itself create a problem. From Popper's theory we can paraphrase the following hypothesis: *All problems seek solutions that create new problems.* As society endeavors to solve today's problems, we do not have the luxury of creating even bigger ones, directly or indirectly, intended or unintended. Therefore it is incumbent that researchers ask: what are the possible problems that our current theories and solutions may create in the short or long term?

Popper's method of conjectures and refutations offers a new way of critiquing existing theories and, in future work, evaluating the tools of Lean Construction as they are applied to solving real problems.

Keywords: Conjectures and refutations, lean construction, theory

Introduction

If Popper's method of conjectures and refutations is applied, any solution creates a new problem, one that is often not anticipated by the problem solvers. We can formulate a hypothesis from Popper's theory: *All problems seek solutions that create new problems*. I test this hypothesis on selected writings from the emerging body of theory applied to construction, focusing on the peer reviewed and published work authored or co-authored by Lauri Koskela, a pioneer in the field of Lean applied to construction, and published between 2000 and 2007. There is no concatenation of Koskela theories in the proposed set of manuscripts, and each one could be analyzed independently. The current set of manuscripts showcases how we can apply Poppers method not only to theories and eventually to practice. For example in the near future we could apply

[1] José L. Fernández-Solís PhD, Department of Construction Science, College of Architecture, Texas A&M University, 3137 TAMU, College Station, TX 77843 U.S.A. jsolis@tamu.edu 1 (979) 458-1058

Popper's method to the work of Ballard and Howell with their methods, tools and techniques (Ballard et al 2002) to anticipate the problems that may be created by the proposed solutions and applications. My paper goes beyond problems and proposed solutions and reaches out to the problems that the solutions create. This work is deliberately incomplete to inspire critical thinking.

Method

The method used is Popper's (1972) "Method of Conjectures and Refutations" (see Fig. 1).

$$P_1 \rightarrow TT_1 \rightarrow EE_1 \rightarrow P_2 \rightarrow TT_2 \rightarrow EE_2 \ldots$$

Figure 1: Popper's Analytical Process of Conjectures and Refutations

Where:

P_1= Original Problem

TT_1= Tentative Theory

EE_1 = Error Elimination

P_2 = Emerging Problem

Anapplication of this technique to selections of Koskela's theoretical work in the industry yields inferences and implications that are otherwise obscured in the drive to solve problems.

Review and Analysis of Emerging Research in Construction

The following framework for analyzing the chosen papers is used:

Causal Loop Analysis:

- Summary of the publication
- Problem identification: Inference about why the statements in the work were made
- Proposed solution(s): Identification of arguments
- Theory development: What was developed, i.e. critical thinking
- The problem created by the solution: Gut reaction to the solutions (critical conjectural thinking)

Popper's conjectures and refutation:

- Application of Popper's schematic formula to identify the problem, the solution and the emerging problem

Koskela, L. (2000) "An exploration towards a production theory and its application to construction"

Koskela's doctoral dissertation describes a search for a theory of production. His work posits that a theory of production in building construction embodies the concepts of transformation, flow and value. The underlying premise is that construction productivity lags behind that of manufacturing. According to Koskela, a crisis or a pre-crisis state exists in the construction 'industry'.

In Koskela's view, this productivity lag is somehow related to the lack of a theoretical foundation in construction, and deemed to be a barrier to progress.

Most of the concepts initiated and presented in Koskela's dissertation are further developed in the subsequent articles and therefore are not treated in detail at this time.

Why were these statements made?

Thediscrepancy between productivity in construction with that in other industries, such as manufacturing, prompted the statement that construction productivity lags behind that of manufacturing because, according to Koskela, there is a lack of a theoretical foundation in construction production.Construction peculiarities [on-site, one-of-a-kind (i.e., unique-product production, Drucker 1963; or prototype nature), and temporary organization] are also determining factors for this lag in productivity. Carassus (2004) further elaborates the characteristics of construction:

- Products are static on-site (immobile): a trait of construction
- Structures are prototypes adapted to each site and environment
- Structures have a very long life (relative to other manufactured products)
- Structures are adapted to evolving demands
- Institutional rules play an essential role

Furthermore, according to Lundin & Söderholm (1995) and Lundin & Steinthórsson (2003), 'action' is identified as 'the essence of temporary organizations.' Others further define construction temporality as: 'temporary multiple organizations' (Cherns & Bryant 1984) or a 'quasi-firm' (Eccles 1981).

Koskela posits that construction, even with its differentiating peculiarities, is an 'industry' (Groák 1994; Bennet et al 1998; Bowley 1966; Dubois & Gadde 2002), and as such can be directly compared with other industries. This basic premise will be challenged in the following studies and observations.

What are the author's arguments and proposed solutions?

Koskela argues that manufacturing techniques and frameworks are not directly translatable to construction, due to its peculiarities. However, if the manufacturing concepts of transformation, flow and value (T, F, V) are incorporated, a theory of construction production could be achieved, one that is sensitive to construction's peculiarities, thus ameliorating the problems caused by discontinuities, constraints and variabilities.

What did the author develop?

Koskela developed a method for highlighting construction peculiarities, based on current practices (mostly transformation), some applications of the flow concept and the even rarer application of the value concept.

Gut reaction to particular issues.

Construction, as practiced, is broader than just a theory of production, and involves many other disciplines, as acknowledged by Koskela. A basic interpretation of construction as an "industry" is Koskela's basis for comparison with other industries, such as manufacturing. Several studies have highlighted the similarities and differences between construction and the shipbuilding, electronics, aerospace (Green et al 2004; Voodijk & Vrijhoef 2003) and automobile (Barber et al 1998; Gann 1996) industries.

However, the differences (construction as an industry of industries, a complex meta-industry, rather than an industry) are at the core of the problem. This differentiation, along with an unidentified construction body of theories, may be the root cause that prevents a direct transference of other industries' techniques and theories to the construction sector in general, as well as in particular projects.

If this is the case, importing technologies, techniques and frames from other industries may prove to be more difficult than anticipated, a continual source of ill fit. The peculiarities, the lack of a theory of production, and the anomalies found in this comparative work point to a higher level of crisis: the need to identify a building construction body of theories that better reflects building construction's background, field and peculiarities.

What Koskela points out in his dissertation, and in subsequent studies, is the presence of an anomaly. Construction embodies technologies (theory and action) with embedded scientific principles with anomalies and violations of expectations. Kuhn (1962) states that: "The manner in which anomalies, or violations of expectations, attract the increasing attention of a scientific (research) community needs detailed study, as does the emergence of the crises that may be induced by repeated failure to make an anomaly conform."

The issue of anomalies in building construction is further discussed in Ballard & Howell (2004): Howell et al (1993a, 1993b; Ballard 1999, 2000) central concept regarding project ends and means is the combined impact of work flow variability and dependence, and their implications for the design of operations. Later, Ballard (1994), Ballard & Howell (1994), and Howell & Ballard (1994a and 1994b) began publishing measurement data on work flow variability. The first data showed 36% failures to deliver on commitments (i.e. 36% of assignments on daily, weekly or aggregated in project duration work plans were not completed as planned). The data is now tracked through a tool called Percent Planned Complete (PPC).

Later publications (Ballard and Howell 1998 a, b) expanded the data set, revealing a 54% average plan failure rate over a wide range of projects and project types. The data, according to Ballard and Howell (2004), represent what they term as a paradigm-breaking anomaly for traditional project management: variation was in fact not spasmodic but persistent and routine. Neither was it small. What's more, according to the authors, analysis revealed that the large majority of plan failures were well within contractor control, contradicting the traditional assumption that variability stems from external causes. This failure to actively manage variability became visible, as did the corresponding need for active management of variability, starting with the structuring of the project (temporary production system) and continuing through its operation and improvement, a target of the Lean Construction trend and initiative. Koskela responds to the issue of this anomaly with a question, the subject of our next inquiry.

Applying Popper's method of conjectures and refutations:

P_1= Construction productivity lags behind that of manufacturing; a crisis or a pre-crisis state exists in the construction 'industry.'

TT_1 = A search for a theory of production that is based on T, F & V concepts

EE_1= Eliminate variation and the causes of variation

P_2= Variation are mostly caused by human conditions, elimination of the cause of variation requires the elimination of human intervention in construction, a societal problem is created when construction remains one of the native industries

Koskela, L 2002, "We Need a Theory of Construction"

Koskela elaborates that "during the next decade, the formation of a theory of construction will be the single most important force influencing the construction industry." This theory, he proposes, will consist of two parts: first, a theory of production in general (T, F & V); second, the application of this theory to the characteristics and peculiarities of construction (on site, one-of-a-kind and temporary organization). On the most general level, Koskela identifies three possible prescriptive actions to a theory of production: design the production system, control the production system (Gilbreths & Gilbreth 1922) and improve the production system.

Likewise, the author identifies three broad-based deficiencies in reaching a theory of construction. First, chronic performance problems can more or less be associated with problems of theory. Second, with the lack of explicit theory, it has been difficult to implement methods of flow and value management in construction. Third, our efforts to develop construction, say through industrialization or information technology, have been hindered by the lack of theory.

These three themes are discussed in detail within Koskela's framework for analysis. The idealized transformation view has a high realization error in complex practice since 'certainty' does not prevail in construction. The inherent variability in production degenerates into mutual adjustments by the team on site. Inherent variabilities, again, are due to the peculiarities in construction. Koskela answers the question of why with: "The various initiatives, such as 'industrialization' and 'information technology' in construction have often failed to produce the results intended because the fundamental problem is theoretical."Halpin (1993) echoes:"we have not gone far enough in seeking a basic framework for the construction of facilities." This study abruptly concludes that using the Last Planner method (Ballard & Howell 1998a) can lead to manifest performance improvement by using transformation, flow and value theory as foundation, but then a method is not a theory.

Why were these statements made?

Halpin's (1993) and Koskela's progressive discovery of the cause of the problems and anomalies in construction leads to the statement that chronic performance problems can more or less directly be associated with problems of theory. A search for the points of a proper theory of construction continues, but appears to be limited by the frame of a theory of peculiarities.

What are the author's arguments and proposed solutions?

Last Planner appears to better integrate the T, F & V concepts and therefore is a better candidate, in the eyes of Koskela, to find an integrated theory of production.

What did the author develop?

Koskela continues relating performance problems to theoretical problems, which is a higher level of analysis than comparative performance of any one industry against building construction performance. Koskela also developed a method for stating that current trends and initiatives for change are neither radical nor sufficient to engender significant structural changes.

Gut reaction to particular issues.

Arguing that the idea that during the next decade, the formation of a theory of construction will be the single most important force influencing the construction industry, Koskela insinuates that there can be a total theory of construction and not just of production.

What we have here is described by Kuhn (1976) as a functioning but unidentified paradigm with rules and theories that are implicit but not explicit to the paradigm: "Rules derive from paradigms, but paradigms can guide research even in the absence of rules." (Theories are derived from rules and vice versa.) Lack of a standard interpretation or of an agreed-upon reduction to rules will not prevent a paradigm from guiding research; indeed the existence of a paradigm need not even imply that any full set of rules exists (Polanyi, 1974 as quoted by Kuhn 1976). Paradigms may be prior to, more binding, and more complete than any set of rules for research that could be unequivocally abstracted from them. Normal science is a puzzle-solving activity that is a highly cumulative enterprise, eminently successful in its aim and the steady extension of its scope and precision.

The distinction between discoveries (novelties of fact) and invention (novelties of theory) is exceedingly artificial. Discovery commences with the awareness of anomaly, i.e., with the recognition that nature (in our case, standards of practice) has somehow violated the paradigm-induced expectations (even though a paradigm has not been currently identified) that govern normal science. It then continues with a more or less extended exploration of the area of anomaly and closes when the theory has been adjusted so that the anomalous becomes the expected.

In construction, then, the anomalous standards of practice indicate that work needs to be done at all levels (practice, theory, rules) up to and including the identification of the existing paradigm in construction.

Applying Popper's method of conjectures and refutations:

P_1 = Need a theory of construction

TT_1= Need a theory and an applied theory: 1. Production in general, 2. Applied to building construction peculiarities

EE_1= Design, control and improve production systems through Last Planner incorporating T, F, & V

P_2 = Certainty does not prevail in construction; on site team adjustments prevail; owner introduced chaos remains possible; current trends and initiatives are not sufficiently radical to render significant structural changes (i.e. may need more manufacturing-like controls)

Koskela, L & Howell, G 2002a, "The Underlying Theory of Project Management is Obsolete"

This study advances the position that there is a theory of project and a theory of management as espoused in the PMBOK (Project Management Body of Knowledge) guide of the Project Management Institute (PMI) (Duncan 1996; Kerzner 2001). Koskela (2002) analyzes the anomalies (deviations from assumptions or outcomes) between theory and practice to conclude that a wider and more powerful theoretical foundation is needed. Why? Mastery of theory, according to Fugate and Knapp (1998) is the single most important factor distinguishing a profession from a craft. Theory is the differentiator of science from craft, of the common view of construction as a field of 'know-how' rather than a field of'know-why'.

Kloppenburg & Opfer (2000) analyzed forty years of project management and found an omission, of the theoretical. Koskela & Howell (2002b) contend, however, that there is an implicit and narrow theory that may explain the following points: frequent failures (Kharbanda & Pinto 1996); a lack of commitment to project management methods (Forsberg et al 1996); and the slow rate of methodological renewal (Morris 1994).

A theory consists primarily of concepts and their causal relationships (Whetten 1989) and, in the case of construction, 'prescriptive' action and exploring how action contributes to the goals set for construction. On the most general level, there are three possible actions: design the systems employed in designing and making; control those systems in order to realize the production intended, and improve those systems.

Koskela & Howell argue that the underlying theory of project management is essentially based on economic transformation theories where, in addition to the ten PMBOK core planning processes (scope planning, scope definition, activity definition, resource planning, activity sequencing, activity duration estimating, cost estimating, schedule development, cost budgeting and project plan development), there is one executing process, and two controlling processes. Thus "Managing is Planning."

By assuming that translating plan into action is the simple process of "issuing orders," *it makes plan production essentially synonymous with action*. This is done through work authorization (like job dispatching in manufacturing, Emerson 1917); selecting a task (per plans); communicating the authorization; and a feedback mechanism of performance reporting (Hofstede 1978; Ogunnaike & Ray 1995). Management at the operations level consists of the centralized creation, revision (updating) and implementation of plans.

Transformation theory, according to Koskela& Howell, presents anomalies when theory encounters the real (empirical) world. In order to evaluate a theory, a comparison is made between alternative theories such as flow and value theories (Koskela 2000). In summary, the major difference between the transformation view and the flow view (i.e. Just In Time (JIT), Gilbreths & Gilbreth1922; Hopp & Spearman 1996; and Lean Production, Alarcon 1997; Ballard & Howell 1998a; Santos 1999) is that the latter includes 'time' as one attribute of production. Because time is affected by uncertainty (Howell et al 1993a) in the production process as well as interdependencies between tasks, the focus of the anomalies is directed towards uncertainties and linkages which are not acknowledged in the transformation view.

Applying Popper's method of conjectures and refutations:

The flow view's basic thrust is to eliminate waste from the flow process, that is, through reducing uncertainty, whereas the transformation view accepts existing uncertainty. *For example JIT and Lean Production can be analyzed as follows:*

P_1 = Management as planning with execution (dispatching: selecting tasks and authorization) and controlling via feedback (thermostat model) closes a loop that leaves out the element of time and uncertainties and is wasteful in practice

TT_{1a} = Time compression leads to waste reduction

TT_{1b} = Variability reduction leads to waste reduction

EE_1= Planning when implemented consists of tasks in time: eliminate time associated uncertainties (**TT_{1a}**) as well as uncertainties associated with the interdependence between tasks (**TT_{1b}**).

P_2 = Externalities and peculiarities continue to introduce uncertainties, variability. JIT and Lean Production depend, to some extent, on production excess capacity and availability on demand. The issue remains of production and material flow control with no attention to the issue of value generation.

The value generation view is based on reaching the best possible value from the customers' point of view (Shewhart 1931; Cook 1997; Suh 2001). The major difference between the transformation view and the value generation view is that the customer is included in the latter. Whereas the transformation view assumes that customer requirements exist at the onset (scope of work definition) and can be decomposed along with the work, the value generation view admits that at the onset, customer requirements are not necessarily available or well understood and that the allocation of value requirements to different parts of the project is a difficult problem (especially given a fixed budget).

Koskela (2000) argues that these three views (T, F & V) are not alternative, competing theories, but rather partial and complementary. What is needed is a production theory and related project management theory that fully integrate the transformation, flow, and value concepts.

In this study, the authors also contrast the theory of control, referred to as the thermostat model, with that of a continuous learning and improvement model. The second theory is based on the idea of a project plan being a hypothesis that is tested through the project itself, which becomes an experiment characterized by the peculiarities of one-of-a-kind by a varying team on a particular site and therefore with multiple variables. *The final product is a comparative analysis of the project (experiment results) with the hypothesis (*Shewhart & Deming 1939*).*

P_1= Plans are hypotheses to be tested in a project experiment

TT_1= Building Design and Construction is a dynamic process of acquiring knowledge

EE_1= An attitude of controlled experimentation with the plans as a guide and with defined purposes.

P_2= Variability of teams entails that lessons learned are not irreversible or transferable to the next project team which may not possess interest and receptivity to issues that have not yet become critical.

The authors argue, along with Wiest & Levy (1969), that it is questionable whether the precedent relationships of project activities can be completely represented by a 'non-cyclical' network graph in which each activity directly connectsto its immediate successors. The overall effects of revisions, repairs and rework on large projects is significant (Cooper 1993; Friedrich et al 1987).

In conclusion, Koskela & Howell state that "Without an underlying theory, it is almost impossible to access deficient assumptions or argue about methodology"

"Project management as a discipline is in crisis," states Koskela (2002a), and a paradigm change, long overdue, must be realized

Koskela & Howell propose two routes for a new theoretical foundation:

- Based on new theories of operations management, new project management methods may be developed and tried out and
- Advanced practice may be consolidated and explained theoretically.

Why were these statements made?

Koskela& Howell analyze the theory of project and the theory of management and continue to issue a call that a wider and more powerful theoretical foundation is needed.

In this paper, the theory of project assumes the same elements of the previously mentioned theory of production. Koskela & Howell may be purposefully equating "project"with"production," although this direct relationship is not explicit, other than describing a theory of "project" by the T, F & V components also used in a theory of production.

What did the authors develop?

Under the umbrella of an underlying theory of project management, Koskela& Howell group the following current topics as taught in academia: (1) a theory of project, (2) a theory of management, (3) a theory of planning, (4) a theory of execution and (5) a theory of controlling. All five theories are then contrasted with the empirical evidence gathered from practice in order to define anomalies. In their Exhibit 2, the authors state that deficient definitions of planning, execution and control, as well as an implicit theoretical basis, are the root causes of the three types of problems previously mentioned. The final call is to create a more intimate relationship between theory and practice, in order to mitigate the serious anomalies found.

Gut reaction to particular issues.

"Mastery of theory," according to Fugate & Knapp (1998),"is the single most important factor distinguishing a profession from a craft." This statement applies to the theory of project management. Koskela & Howell do not acknowledge that the divisions within the fragmented construction field have fully developed theories according to their professions. For example, there is a well developed theory of structures and theory of mechanics (includingclimate comfort as well as physical comforts, such as plumbing).

The authors look at the narrow scope of putting a project together and, by addressing the issue of planning, they have suggested a fundamental principle: *plan production is essentially synonymous with action*. In the past, when architecture or design became differentiated from construction, the same critique was made about design plans, assumed to be essentially synonymous with action. Now we have another layer of planning, construction management planning, which is also essentially synonymous with action. It is even argued that sub-contractors have become another layer (sub-contractor planning) that is also synonymous with action, further relegating actual production and assembly to a sub-sub echelon. "The delegation appears to be a winding road to China…" The principle that planning is essentially synonymous with action may play a significant role in the actual paradigm. Joachim Knuf, unpublished, observes that planning is a representational and regulative metaaction to construction action and that a theory of construction can comprise other metalevels as well, such as a human factor metalevel that explains the interpretive effort of individuals and groups/teams as they conceive of and make decisions about the relationship between plan and construction activity. Planning is directive; it is a vector, not a structural element in the theory.

No doubt, there is a crisis (comparing building construction productivity with that of other industries) and a blurring of where solutions may be found (such as a body of theories that can be tested and refined). Koskela and others are voices documenting the anomalies and the magnitude of the crisis. However, the proposed solutions remain within the existing and unidentified paradigm, as something apparently is not working.

The unidentified paradigm in building construction may be an implicit and deeply embedded paradigm difficult to grasp, although once identified becomes obvious. This assumption is made because building construction practice is so ancient (building a shelter from the forces of the natural environment), and predates any figment of a conscious understanding of science, technology, techniques, craft, frame of reference, field, background or the concept of paradigm.

Kuhn (1962, 1976, 2000; et al 2003) observed that: "All crises begin with the blurring of a paradigm and the consequent loosening of the rules for normal research." In our case, it could be the blurring of the embedded building construction paradigm with the assumption that it is the same or synonymous with the industrialization paradigm (Ballard and Howell 2003a). In this respect, research during crisis very much resembles research during the pre-paradigm period, except that in the former the locus of difference is both smaller and more clearly defined. All crises close with the emergence of a new paradigm and with the subsequent battle over its acceptance. This battle is a reconstruction of the field from new fundamentals, a reconstruction that changes some of the field's most elementary theoretical generalizations as well as many of its paradigm methods and applications.

Kuhn (1976) observed that it is particularly in periods of acknowledged crisis that scientists have turned to philosophical analysis as a device for unlocking the riddles of their field; this is the thrust of this paper. Scientists have not generally needed nor wanted to be philosophers. Indeed, normal science usually holds creative philosophy at arm's length, and probably for good reason. It is no accident that the emergence of Newtonian physics in the seventeenth century and of relativity and quantum mechanics in the twentieth should have both been preceded and accompanied by fundamental philosophical analyses of the contemporary research tradition (Dugas 1950; 1954).

The identification of anomalies in the theory and practice of building construction is a major contribution to the field of knowledge. There are only three types of phenomena about which a *new theory* might be developed, according to Kuhn (1962):

- Phenomena already well explained by existing paradigms; however, in most cases nature does not provide ground for discrimination;
- Those whose nature is indicated by existing paradigms but whose details can be understood only through further theory articulation but not invention; and
- The recognized anomalies whose characteristic feature is their stubborn refusal to be assimilated to existing paradigms and thus give rise to new theories.

Koskela and Howell (2002a) identified the third type of phenomenon (see above) as typical of the state of the construction industry.

Koskela, L Ballard, G and Howell, G 2003, "Achieving Change in Construction"

Koskela et al further analyzes selected initiatives in construction regarding a perceived need for change. This paper considers the scope of change needed and the big foundational ideas of change, as well as the initiation of change and keeping its momentum. The paper addresses four questions: First, which kind of change? Second, how are those changes, in principle, achieved? Third, presuming that construction is a fragmentedand fluid industry that cannot be changed overnight, where should change start? Fourth, how can the change momentumbe maintained after it begins?

Regarding the first query, which kind of change? According to Papert 2000, as quoted by Koskela et al, there are two approaches to the renovating school of thought: the problem-solving approach (individual problem solution) and the systemic approach (how the whole thing works). The majority of industry initiatives, according to Koskela et al, address the individual problems in question: cost, productivity (time and cost), quality, safety, and sustainability. First, solutions offered are not expected to lead to reform. Second, the suggested solutions address an underlying and 'obvious' cause of the problems through a pre-understanding of the nature of the problem or opportunity. "The pre-understanding is determined by a person's perspective within the guiding [*professional]* paradigm" (*"professional" added to Koskela's statement*).

Koskela et al analyze four commonly understood kinds of change: structural, behavioral, communications (information management) and physical (machinery). Solutions to problems found in building construction are exemplified by design-build as a structural response to the anomalies found in design-bid-build (known as traditional project delivery system). Structural change alone, according to Koskela (2003a), does not provide a solution, such as the structural change to the project delivery system (PDS) accomplished by adding design-build to a model that originally was dominated by design-bid-build.

Why is change in the construction industry so difficult to realize? Dubois & Grade, (2002) and Groák (1994) have a possible opinionated explanation: "Construction cannot be considered a coherent industry with definable boundaries and characteristic problems" Groák (1994). Therefore we have a lack of fit between trying to mold a construction paradigm to other industries and its inherent reality.

Applying Popper's method of conjectures and refutations (to PDS)

P_1= Systemic structural change required for the project delivery system, overriding concern with cost and resulting conflicts

TT_1= One contract incentive for cooperation between design and builders

EE_1 = Unify design and builder into one contract to eliminate design-builder conflict reflecting on the owner (sidetrack the Spearing Doctrine where the owner, through the designer, provides documents that are adequate and sufficient for construction)

P_2 = Performance is equal to the traditional Design-Bid-Build in terms of cost, time, quality and sustainability results, since the intrinsic mode of operation between the designer and the builder (their respective behavior, practice and cultures) does not change with a project whose peculiarities are one-of-a-kind and by different teams, therefore lacking efficient teamwork. Lack of integration of design and building cultures (behavioral approach) fails to achieve higher expectations of efficiency and effectiveness.

The behavioral approach is based on the mentality (attitude, behavior, practice, culture) and motivation of people as the root of the problem. Teamwork and partnering are suggested solutions to increase cooperation by identifying shared goals and establishing communication rules. *For example, we now add the process called partnering to a Design-Build project team:*

P_2 = (The new starting point) Design-Build Performance is relatively equal to the traditional Design-Bid-Build in terms of cost, time, quality and sustainability results since the intrinsic mode of operation between the designer and the builder (their respective practice, behavior, and culture) does not change, therefore lacking efficient teamwork

TT_2= Agreement on Project Success Criteria increases teamwork efficiency (behavioral and inter-firm cooperation)

EE_2= Problem resolution scale (resolve problems at the lowest level of competency within a prescribed and strict time period)

P_3= Non-Binding Charter; Higgins and Jessop (1965) "any lack of cohesion and coordination is less the result of ill-will or malignancy on the part of any groups or [individuals] but more the result of forces beyond the control of any individual group and which are affecting all."

In order to identify early the forces that are beyond the control of any individual, the stakeholders are then asked to participate in the process called Project Definition Rating Index (PDRI) (Cho et al 1999; Durmont et al 1997). They are also asked for increased commitment, an investment to improve communications via technologies (see item 3.9 below) and they make the owner aware of the chaos that changes can create during the process. Communications (Information and Communication Technology - ICT) is based on the premise, or the belief, that access to information and clarity of communications is the issue.

However, according to Koskela et al, new technology does not change the more fundamental way work is done (Koskela & Kazi 2003). An Ekstedt and Wirdenius (1994) study finds that construction behavioral-cultural programs, in comparison to those in manufacturing, are easier to implement but with limited real results. Higgin and Jessop (1965) report that lack of cohesion and coordination is the result of forces beyond the control of any individual or group, yet it affects all. That is, the system in practice (or context) has externalities that determine behavior. Trying to change behavior (one-of-a- kind, temporary organization) is more or less futile. *The following is an example, an analysis of ICT using the same format:*

P_{ict1} = Access to clear, correct, complete and timely information in an ambience of deteriorating design documentation and quality due to reduced fees (Tilley & McFallan, 2000)

TT_{ict1}= One platform, web based, with shared real time information and accessible to all stakeholders on demand increases efficiency by reducing discontinuities, constraints and variability in the planning phase. Planning and execution efficiencies are deemed synonymous.

EE_{ict1} = Eliminate duplication of outdated information and avoid discontinuities and variabilities in document generation and use

P_{ict2} = Difficult to implement due to the cost and the learning curve of one platform when stakeholders are accustomed to their own platforms. For ICT benefits to be unleashed there must be: upstream support of organizational changes to owner, financial institutions, and code officials; downstream to each sub-contractor, supplier and vendor. Implementing a translator of existing platforms with one web-based platform, so that each stakeholder can use both, is prohibitive due to the peculiarities of one-of-a-kind and temporary organization (Lundin & Söderholm 1995; Lundin & Steinthórsson 2003).

Physical (machinery) problems are associated with the low level of mechanization and either industrialization (off-site pre-fabrication) or on-site construction robotics and automation. *The belief behind this issue is that industrial production is more efficient as shown in the following example:*

P_{m1}= Low level of mechanization

TT_{m1}= Industrial production is more efficient through the use of robotics and automation that eliminates human induced variability and waste, thus bringing the efficiencies in planning to bear directly on execution, making real the previous theory that planning and execution are synonymous. The underlying theory is that "perfect – correct, complete, coordinated and timely" planning by both design and construction management translates into perfect execution.

EE_{m1}= Eliminate down time, by robotics that can work 24/7/365, control of variables and elimination of internal and external discrepancies, conflicts and the resultant waste.

P_{m2} = Coordination issues with other trades remain unless the whole project can be done with robotics and automation. ICT flow through one-of-a-kind project, on site and by differing teams requires a universal platform where activities and parts brought by suppliers and vendors are integrated; that is, the whole production template is changed. Apparently this radical change is cost prohibitive due to project peculiarities, especially one-of-a-kind, where increased complexity and cost does not yield sufficient project benefits and efficiencies for the required investment in time and learning.

Before proceeding with questions two, three and four, the authors discuss the issues of the production paradigm (Ranta 1993; McLoughlin 1999), theories of production and production templates. The authors conclude that "*industrial history indicates that improvements in the range required in construction happen only when the whole production template is changed*." This production template change is based on new big ideas, new theories (*and we add "new paradigm"*).

Answering the first query, Koskela et al state that current trends and initiatives are mainly of the "individual (segmented) problem solving approach" and are based on a divide and conquer mentality (also called the scientific, transformation method, or decomposition).Regarding the problem solving approach in quality assurance, for example, they hold to the principle of constraint removal, the current mental model of production.

The next query posed is: How can the changes, in principle, be achieved? Koskela et al accept the principle that a systemic change is needed in construction; then, how can it be achieved? Construction places its hopes on external ideas as drivers for change, such as industrialization or ICT. Regarding industrialization, the target is to transform construction into manufacturing. Regarding ICT, the premise is that increased use of data sharing via computers/Local Area Networks (LAN)/Wide Area Networks (WAN - internet) will lead to organizational renewal and eventually increased efficiencies and waste reduction. However, both of these initiatives are deemed to increase complexity without benefits. The observation that "something is wrong,"that there are "anomalies" in the current construction paradigm is echoed by Butler (2002) who states that: "Construction has become more and more complex. Disciplines have divided and sub-divided and whole new trades have sprung up. Contractors seldom self-perform a substantial portion of the work. To make matters worse, subcontractors are beginning to do the same by hiring their own subs to do the work" (Allen 1996).

The result of this downstream activity is, according to Bennet and Ferry (1990), a "total lack of production control." Tilley and McFallan (2000) indicate that design and documentation quality has decreased at the same time that project cost, time and inter alia disputations, lower quality and lack of attention to sustainability have increased (Koskela 1992; Howell & Ballard 1997; Koskela 2000). This is attributed, by Koskela et al, to a progressively more forceful application of the transformation model of production: decomposition of the total transformation (the project) into smaller transformations and eventually tasks, then minimizing the cost of each task independently on the basis of the lowest price. This leads to two major problems: first, in the case of planning (design plans and management plans for construction), the completeness, correctness, coordination and timeliness of the documents tend to decrease with decreasing fees. Second, as planning is pushed downstream, the coordination of production control and corresponding variability tends to increase beyond what the project budget can bear.

The construction model (Ballard & Howell 1998a) is a model of *project control, not production control,* according to the "contractual agreement"; thus construction can be said to have no theory of production control proper. The Tavistock Institute (1966) pointed out that the disparity of the formal system (contracts, documents, Project Management, Schedule, Cost Estimating) and the informal system (on site, varying team, management of uncertainties, variabilities, discontinuities, task independence, sub-sub-contractors) in relation to the total task is the root cause of all the problems. The informal system manages a climate of endemic crisis which is self inflicted and self perpetuating. Two solutions are proposed, ICT and behavioral approaches, as previously seen. However, in most cases, the participants become resigned to the notion that no meaningful, real change is possible.

Koskela (2003) argues that a change from transformation to a flow template can be achieved through deliberate design and imitation. In a practical way, theories should explain why problems exist and how they can be avoided (Koskela & Ballard 2003). Experimentation should then be used to translate theories into practical methods and tools.

The next query approached is: Where should change start? Two approaches to this query are presented: first, basing the owner's procurement strategy on performance, rather than cost (Chan et al 1996). Performance is considered at the beginning of a project, where the scope of the project is created (chaos theory states that minor, almost insignificant, deviations at the start end up in crisis). Second, change should start by working with those who actually manage production, the end where the product is created (design, pre-fabrication, erection, on site construction and site personnel). Koskela et al. (2003) argue for starting at the end because this is where cost, time, and quality are concretely formed and because what we learn can be taken upstream.

The final query is: How can change momentum be maintained? The authors address two interrelated levels of change momentum maintenance: the firm and the industry. At the firm level (organizational change, Beer & Nohria 2000), one approach focuses on top-down changes on formal structures and systems to mainly create economic value (thus termed Theory E). The other approach focuses on the development of a culture of high involvement and learning in a participative manner (hence Theory O). Koskela et al propose using both E and O, simultaneously creating 'small wins' (Weick 1994) with each step-by-step change. Through controllable opportunities of modest size that produce visible results and serve as background to identify the next possible problem to solve, a pattern is thus built that attracts allies and deters opponents. The iterative process of problem-solving changes needs to be scrutinized prior to experimentation by the following questions:

- Is there a Plausible Explanation (PE) – at a sufficiently detailed level – as to why the solution would work?
- Is there Empirical Evidence (EE) showing that the solution brings the benefits sought?
- Is the solution self-sufficient or does it require surrounding (ancillary - AN) changes for working efficiently and providing manifest benefits?
- If the solution is imported from another domain, has it been conceptually and Empirically Confirmed (EC) that the solution works in the context of construction?

This iterative process appears similar to Popper's (1972) method of analysis (Conjecture and Refutations) and applicable mostly to individual (segmented) rather than systemic cases. Because it is applicable to individual cases, the following iterative process may now apply:

P_1 = Original Problem

TT_1= Tentative Theory

EE_1= Error Elimination

PE = Plausible Explanation (why it should work)

EE = Empirical Evidence (will achieve expectations)

AN = Self-standing/Ancillary effects

EC = Empirical Confirmation of transferability

P_2= Emerging Problem

In conclusion, Koskela et al argue that:

- A systemic change (not problem specific oriented change) must be achieved for eliminating root causes of the problems
- External ideas or impacts (industrialization and ICT) are not the solution, since a 'new big idea' for managing construction must be found--a new paradigm
- Instead of upstream structural changes (contractor and organizational top-down), we should look at operational changes downstream that create the end product, and work backwards toward upstream settings
- Changes do not occur automatically even in a favorable environment, but through small wins in a fragmented milieu that gather strength and eventually achieve system-wide changes in an entrepreneurial environment.

Why were these statements made?

Current trends and initiatives are neither radical nor sufficient to engender a structural change in the industry, but it remains to be established what kind of change is needed and how these types of changes can be implemented and maintained (Koskela et al. 2003). This paper centers around the research needed to answer four well posed queries with the *a priori* presumption that construction is a fluid industry that cannot be changed overnight, that incorporates a cursory definition of "fragmented." A better definition of how construction is understood to be fragmented or fluid is needed beyond what is presently available through a literature search, for recommended future work or even a possible dissertation topic.

This proliferation of trends and initiatives is not uncommon in a pre-paradigm identification scenario, according to Kuhn (1962): During both the pre-paradigm period and the crises that lead to large-scale changes of paradigm, scientists usually develop many speculative and unarticulated theories that can themselves point the way to discovery. Often, however, that discovery is not quite the one anticipated by the speculative and tentative hypotheses. Only as experiment and tentative theory match does discovery emerge and theory become grounded.

What are the author's arguments and proposed solutions?

Koskela et al acknowledge that a "big foundational idea change" needs to take place if the construction industry is to be changed significantly. Koskela et al analyzed the two change approaches according to Papert (2000): problem-solving approach (individual problem solution) and the systemic approach (how the whole thing works). Afterwards, Koskela et al concluded that a problem-solving approach, from the bottom-up, that acknowledges how things are done, may be indicative of a practice, technique or craft that could be analyzed for pertinent theories that can then be incorporated with an overall frame. However, the validity of this approach must be confirmed by an equally well adjusted flow between paradigm-rules-theories-practice in both the downstream and upstream settings.

The argument is then made that industrial history indicates that improvements in the range required in construction happen only when the whole production template changes. This production template change is based on "new big" ideas--new theories. These statements point to a need to identify the reigning paradigm and establish once and for all what kind of industry building construction it represents, if the term fits and applies, and if not, what building construction is, based on the existing paradigm. When confronted with anomaly or with crisis, scientists take a different attitude toward existing paradigms, and the nature of the research changes accordingly (Kuhn 1962). The proliferation of competing articulations, the willingness to try anything, the expression of explicit discontent, the recourse to philosophy and to debate over fundamentals--all are symptoms of a transition from normal to extraordinary research. This transition could assume any of the following manifestations:

- In principle, a new phenomenon might emerge without reflecting destructively upon any part of past scientific practice; or
- A new theory might be simply a higher level theory than those known before, one that links together a whole group of lower level theories without substantially changing any of them; or.
- In an evolutionary sense, new knowledge would replace ignorance rather than replace knowledge of another and incompatible sort.

From Koskela et al (2003) statements, it appears that their position aligns with Kuhn's statement number 2 mentioned above. We argue, on the other hand, that statement number 3 is more applicable: considering ignorance about what is the prevailing and active construction paradigm, a new basic and probably very simplistic knowledge (such as the earth is round, or that the sun is the center of the universe) may end up being a better accounting of the anomalies and current crisis.

What did the authors develop?

Koskela et al developed a method for analyzing four commonly understood solutions in the areas of structural, behavioral, communications (information management) and physical (machinery) change that we adapted into Popper's Analytical Process (iterative method of conjecture and refutations).

Specifically, Koskela et al elucidated the issues surrounding increasing complexity of the proposed trends and initiatives without significant results. This brings to mind Kuhn's (1976) statement: "When complexity increases far more rapidly than its accuracy or benefit and that a discrepancy corrected in one place is likely to show up in another may lead to a similar proclamation as that of Alfonso X that if God had consulted him when creating the universe, he would have received good advice, or Copernicus comment in *De Revolutionibus* that the astronomical tradition he inherited had finally created only a monster." "Proliferation of versions of theories is a very usual symptom (or concomitant) of crisis" (Kuhn 1976).

The acknowledgement that construction is a fragmented industry is one of the more significant insights or statements made, along with the differentiation of formal planning, as per Project Management, and informal planning, as per the job trailer executors—the operators. The discrepancies, variabilities and constraints between these two modes of planning (actually he calls Project Management planning and on-site work executing or implementing), along with the concept of fragmentation in the construction 'field' is significant to an understanding of actual operations and may lead to insights about the existing paradigm. Carassus (2004) observes: "Fragmentation is determined in particular by three factors: fragmentation of the order, the degree of technical complexity and the capital intensity of the activity." Each segment of the 'sector system' contains a large number of companies. He calls this "differentiated fragmentation".

Gut reaction to particular issues.

The current reading has added to the issues of discontinuities, variability, constraints, peculiarities, and lack of theory, the issues of fragmentation and the anomalies innate in current concepts of planning.

Koskela, L 2003a, "Is Structural Change the Primary Solution to the Problem of Construction?"

Koskela analyzes the causes for the well known problems of construction. A number of renewal initiatives such as industrialization, open building, design-build, partnering, re-engineering, Just in Time, Lean Construction and others are mentioned or analyzed. These initiatives imply or claim to be structural changes to the organizational pattern and/or the flow of information and materials. Koskela proposes a theoretical framework in order to discuss the issue of structural adequacy of these initiatives composed of three main theories (1) production, (2) management and (3) peculiarities in the building construction industry (Nam & Tatum 1988; Riis et al 1992; Wortmann 1992a and b; Wortmann et al 1997), as follows:

This framework is composed of a theory of production (incorporating the afore-mentioned concepts of transformation, flow and value –T, F & V), a theory of management and conceptualization (design, operations and production system improvements), and a theory of the peculiarities of construction (on site, one-of-a-kind and temporary organization). Based on this framework, a number of conclusions are drawn:

- Due to its peculiarities, construction is characterized by a high level of variability (one role of management is to stem the penalties due to variability and the further propagation of variabilities).
- All renewal initiatives have shown modest, and at times, disappointing, results.

Although Koskela admits that the causal relationship of such disappointments cannot be definitively established, he suggests that the neglect of changes at the level of operation and improvement contribute to the lack of results. Therefore, he argues, we "need to develop further the theoretical foundations or first principles, of production in general and especially in construction."

Why were these statements made?

Based on his dissertation, in this study, Koskela analyzes select trends and initiatives in construction that address the well known problems of construction. Problems or identified anomalies are the starting point of the argument that says well intended structural changes to the organizational pattern and/or the flow of information and materials fail to achieve the desired results, viewed from the framework of his production theory (T, F & V) and the peculiarity theory (on site, one-of-a-kind and temporary organization).

What are the author's arguments and proposed solutions?

Koskela's proposed solution is to highlight the need to further develop the theoretical foundations, or first principles, of production in general and especially in construction. The theoretical foundation, however, still looks to manufacturing for guidance, frame of reference and theories (Heim & Campton 1992; Hopp & Spearman 1996).

What did the author develop?

Koskela's thrust, in order to correct the neglect of changes at the level of operation and improvement, is to highlight the need for a more integrated theory of production based on the T, F & V concepts. The difficulty of establishing causality is acknowledged by Koskela, but the issues, even if they are muddied, are real and merit confrontation. Kuhn (1976) acknowledges the immense difficulties often encountered in developing points of contact between theory and practice, especially when the underlying worldview does not allow for a clear and obvious connection of theory to practice, which may be the current case. What appears to be taking place throughout these studies is a preliminary identification of the puzzle, or parts of the puzzle that could lead to worldview (paradigm) identification. Joachim Knuf, unpublished, observes that Kuhn's work is really about paradigm shift; so part of the problem, I believe, is that there does not exist an actual paradigm of current practice that has good internal validity. It's like manufacturing, where people want to improve their process but do not work from a stable platform, just going about changing things.

Gut reaction to particular issues.

Per Kuhn (1976), we see building construction's search for an identification of deficiencies and anomalies and a concerted attempt to incorporate the technologies, frame and theories of production that continue to rub against the grain of a theory of construction peculiarities. Adding complexity to a system without significant results is a sign that the working paradigm is not properly attuned to the circumstances; however, as mentioned, there have been few attempts in the literature (Ballard & Howell 2003a; Groák 1994; Ranta 1993) to identify an existing building construction paradigm.

Applying Popper's method of conjectures and refutations:

P_1= High level of variability perceived as an anomaly

TT_1= Need for a theoretical foundation or first principle of production in general and specifically of building construction, based on theories of:

1. Production,
2. Management, and
3. Peculiarities

EE_1= Eliminate variabilities and the propagation of variabilities

P_2= No clear and obvious relationship exists between theory and practice, but levels of complexity are added to the process; possible crisis and realization that the current paradigm (building = manufacturing) cannot resolve the anomalies and crisis.

Conclusions

Bury (1932), as quoted by Mitcham (1994), observed, "The spectacular results of the advance of science and mechanical technique brought home to the mind of the average man the conception of an indefinite increase of man's powers over nature as his brain penetrated its secrets. The evident material progress which has continued incessantly ever since has been a mainstay of the general belief in progress that is prevalent today." Progress in the construction industry can be discerned primarily by looking at the industry itself. However, change in a fragmented and complex industry is difficult to achieve, since data collection mechanisms are not in place. On the other hand, emerging research, initiated primarily by academicians, is a valid surrogate for the current arguments, theories and analysis of practices in the industry.

This surrogate research in construction through academic work can be characterized as mostly dealing with the "know how." Recent publications have portrayed the lack of theory, or "know why" as a blind spot in our knowledge and perhaps a source for the lack of progress towards efficiency in the construction industry. When a segment of emerging research, dealing in particular with the topic of theory in construction, is analyzed, a mosaic of the industry can be perceived, albeit subjectively. Furthermore, we can gauge if the solutions being contemplated are incremental, step or radical new knowledge that can translate into innovative technologies and techniques.

The theory of conjectures and refutations is a unique means to critique current theories by challenging researchers to find a solution that does not in itself create a problem. Popper's theory formulates the following paraphrased hypothesis: All of our current problems are created by the solutions to past problems. As we endeavor to solve today's' problems, we do not have the luxury of creating even bigger ones, directly or indirectly, intended or unintended. Therefore it is incumbent upon us to ask about and make transparent the possible problems that our current theories and solutions may create in the short or long term.

Popper's method of conjectures and refutations is submitted as a useful and valid gateway into a new way of critiquing current theories and in future work, evaluating the tools of Lean Construction as they are applied to solving real problems.

We are, at this time, calling for radical, new insights and innovation that are tamed by awareness that the solutions to current problems and crises do not have the luxury of creating even bigger problems in the future. Popper gives us a mechanism to filter our solutions and seek what lurks behind them, thus helping us make better decisions.

References:

Alarcon, L (ed.), 1997, *"Lean Construction,"* A.A. Balkema, Rotterdam, the Netherlands 497 p

Allen, C 1996, *"Value Judgment,"* New Civil Engineer, 7th November, pp18-19.

Ballard, G 1994, *"The Last Planner,"* Northern California Construction Institute Spring Conference, Monterey, CA, April

Ballard, G 1999, *"Can Pull Techniques be Used in Design Management? Concurrent Engineering in Construction: Challenges for the New Millennium,"* CIB Publication 236,VTT, Espoo, 149-160

Ballard, G 2000, *"The Last Planner System of Production Control,"* Ph D thesis, Faculty of Engineering, University of Birmingham, 192p

Ballard, G & Howell, G 1994, *"Implementing Lean Construction: Stabilizing Work Flow,"* Proceedings of the 2nd Annual Meeting of the International Group for Lean Construction (IGLC), Santiago, Chile (Available in Lean Construction, A. A. Balkema Publishers, Rotterdam, Netherlands, 1997).
Ballard, G& Howell, G 1998a, *"What kind of production is construction?"*Proc. 6th Annual Conference of the IGLC, Guarujá, Brazil, August 13-15
Ballard, G & Howell, G 1998b, *"Shielding production: Essential Step in Production Control,"* Journal of Construction Engineering and Management 124 (**1**)11-17
Ballard, G& Howell, G 2003a, *"Comparing Construction Management Paradigms,"* ASCE Construction Research Congress, Honolulu, Hawaii, March 19-21, 2003, 8p.
Ballard, G & Howell, G 2004, *"Competing Construction Management Paradigms,"* Lean Construction Journal 1(**1**)38-45.
Ballard, G; Tommelein, I; Koskela, L; Howell, G 2002, *"Lean Construction Tools and Techniques,"* In Best, R., and de Valence, and G., (eds.) Design and Construction, Building in Value, Butterworth-Heinemann, Oxford, 227-255.
Barber, P R; Sheath, D M; Walker, S; Graves, A.P; Tomkins, C.R 1998, *"A Comparison of Design Management Techniques in Construction and the Automotive Industry,"* in Amor (ed.): *"Product and Process Modeling,"* Building Research Establishment, Watford, 67–74
Bennet, J & Ferry, D 1990, *"Specialists Contractors: A Review of Issues Raised by Their New Role in Building,"* Construction Management and Economics, 8, 259-283.
Bennett, J; Pothecary, E; Robinson, G 1998, *"Designing and Building a World Class Industry,"* University of Reading, Reading.
Beer, M & Nohria, N (ed), 2000, *"Breaking the Code of Change,"* Harvard Business School Press, Boston, 507p
Bowley, M 1966, *"The British Building Industry,"* Cambridge University Press, Cambridge
Butler, J R Jr 2002, *"Construction Quality Stinks,"* Engineering News Record, March 18.
Carassus, J 2004, *"From the construction industry to the construction sector system,"* In the Construction Sector approach: An international framework, (ed. Carassus, J.) CIB, Publication 293, Rotterdam pp 5-16
Chan, D W M & Kumaraswamy, M M 1996, *"An Evaluation of Construction Time Performance in the Building Industry,"* Building and Environment, 31(**6**)569-578.
Cherns, A B & Bryant, D T 1984, *"Studying the Client's Role in Construction Management,"* (**2**)177-184.
Cho, CS; Furman, J; Gibson, G E 1999, *"Project Definition Rating Index (PDRI) for Buildings,"* A Report to the Construction Industry Institute (CII), The University of Texas at Austin, Research Report 155-11, Nov.
Cook, H E 1997, *"Product Management-Value, Quality, Cost, Price, Profit and Organization,"* Chapman and Hall, London, 411p.
Cooper, K G 1993, *"The Rework Cycle: Why Projects are Mismanaged,"* Project Management Network, February, 5-7
Drucker, P F 1963, *"The Practice of Management,"* Heinemann, London.
Dubois, A &Gadde, LE 2002, *"The Construction Industry as a Loosely Coupled System: Implications for Productivity and Innovation,"* Construction Management and Economics, 20 (**7**)621-631.
Duncan, W 1996, *"A Guide to the Project Management Body of Knowledge,"* Project Management Institute (PMI) Publications, Sylva, NC. 176p
Durmont, P R; Gibson E G; Fish J R 1997, *"Scope Management Using Project Definition Rating Index,"* Journal of Management in Engineering, ASCE, 13(**5**)54-60
Eagan, J 1998, *"Rethinking Construction,"* London, Department of Transport and the Regions.
Eccles, R G 1981, *"The Quasi-firm in the Construction Industry,"* Journal of Economic Behavior and Organization 2(**4**)335-357

Ekstedt, E & Wirdenius, H 1994, *"Enterprise Renewal Efforts and Receiver Competence: The ABB T50 and the Skanska 3T Cases Compared,"* Paper presented at the IRNOP Conference, Lycksele, Sweden, March 22-25, 18p

Emerson, H., 1917, *"The Twelve Principles of Efficiency,"* Fifth Ed.The Engineering Magazine, New York, 423p.

Forsberg, K; Mooz, H; Cotterman, H 1996, *"Visualizing Project Management,"* John Wiley & Sons, New York, 289p

Friedrich, DR; Daly, J P; Dick, W G 1987, *"Revisions, Repairs and Rework on Large Projects,"* Journal of Construction Engineering and Management, 113(3)488-500

Fugate, M & Knapp, J 1998, *"The Development of Bodies of Knowledge in the Professions,"* Appendix B in: "Project Management Institute," *1999 "The Future of Project Management,"* Newton Square, 101-113.

Gann, DM1996, *"Construction as a manufacturing process? Similarities and differences between industrialized housing and car production in Japan,"* Construction Management and Economics, 14(5)437-450

Gilbreths, F B & Gilbreth, L M 1922, *"Process Charts and Their Place in Management,"* Mechanical Engineering, January, 38-41,70.

Green, S D; Newcombe, R; Fernie, S; Weller, S 2004, *"Learning Across Business sectors: Knowledge Sharing Between and Construction,"* University of Reading, Reading, 84p

Groák, S 1994, *"Is Construction an Industry? Notes Towards a Greater Analytical Emphasis on External Linkages"* Construction Management and Economics, 12 (**4**)287-293.

Halpin, D 1993, *"Process-Based Research to Meet the International Challenge,"* Journal of Construction Engineering and Management, 119(**3**)417-425

Heim, J & Compton, W D 1992, *"Manufacturing Systems: Foundations of world-class practice,"* National Academy Press, Washington, D.C. 273p.

Higgin, G and Jessop, N 1965, *"Communications in the Building Industry,"* Tavistock Publications, London, 125p.

Hofstede, G 1978, *"The Poverty of Project Management Control Philosophy,"* Academy of Management Review, July, 450-461

Hopp W & Spearman, M 1996, *"Factory Physics: Foundations of Manufacturing Management,"* Irwin/McGraw-Hill, Boston, 668p.

Howell, G & Ballard, G 1994a, *"Lean Production Theory: Moving Beyond 'Can Do',"* Proceedings, Conference on the IGLC, Santiago, Chile, September.

Howell, G & Ballard, G 1994b, *"Implementing Lean Construction: Reducing Inflow Variation,"* Proceedings, Conference on the IGLC, Santiago, Chile, September.

Howell, G & Ballard, G 1997, *"Lean Production Theory: Moving Beyond 'can do,"* In Alarcon, Luis (Ed) *"Lean Construction,"* Balkema, 17-23.

Howell, G; Laufer, A; Ballard, G 1993a, *"Uncertainty and Project Objectives,"* Project Appraisal, 8(**1**)37-43

Howell, G; Laufer, A; Ballard, G 1993b, *"Interaction between Sub-cycles: One Key to Improved Methods,"* Journal of Construction Engineering and Management, ASCE, 119(4)

Kerzner, H 2001, "Project Management, A systems Approach to Planning, Scheduling, and Controlling," 7th Ed, Wiley, New York, 1203p.

Kharbanda, O P & Pinto, J K 1996, *"What Made Gertie Gallop: Learning from Project Failures?"* Van Nostrand Reinhold, 368p

Kloppenburg, T J & Opfer, W A 2000, *"Forty Years of Project Management Research: Trends, Interpretations, and Predictions,"* Project Management Research at the Turn of the Millennium. Proceedings of PMI Research Conference 2000, 21-24 June, Paris, France, 41-59.

Koskela, L 1992, *"Application of the New Production Philosophy to Construction,"* Center for Integrated Facility Engineering (CIFE) Technical report # 72, Stanford University, Stanford 75p

Koskela, L 2000, *"An exploration towards a production theory and its application to construction,"* VTT Publications 408, VTT, Espoo, Building Technology, 296p

Koskela, L 2002, "*We Need a Theory of Construction,"* VTT, Building Technology, Espoo.

Koskela, L 2003, *"Is structural change the primary solution to the problems of construction?"*Building Research & Information, 31(**2**)85 – 96

Koskela, L; Ballard, G; Howell, G 2003, *"Achieving Change in Construction"* Proceedings of the 11th annual conference of the International Group for Lean Construction, August 2003, Virginia Tech, Blacksburg, VA, 1-15.

Koskela, L & Howell, G 2002a, *"The underlying theory of project management is obsolete"*, in D.P. Slevin, D.I. Cleland and J.K. Pinto (eds.): Proceedings of PMI Research Conference 2002, Project Management Institute, 293–302

Koskela, L & Howell, G 2002b, *"The Theory of Project Management – Problem and Opportunity,"* Working Paper, VTT Technical Research Center of Finland & Lean Construction Institute.

Koskela, L; Howell G; Tommelein, I 2002, *"The Foundation of Lean Construction,"* In Best, R &deValence, G (eds.): *"Design and Construction: Building in Value,"* Butterworth-Heinemann, Oxford, 211-226.

Koskela, L & Kazi, A S 2003, *"Information Technology in Construction: How to Realise the Benefits?"* In: Socio-Technical and Human Cognition Elements of Information Systems. Ed by Clark, S; Coakes, E; Hunter, M G; Wenn, A 2003, Information Science Publishing, Hershey, PA., 60-70

Koskela L &Vrijhoef, R 2001, *"Is the current theory of construction a hindrance to innovation?"* Building Research and Information, 29(**3**)197-207

Kuhn, T 2000, *"The Road since Structure,"* Ed by James Conant and John Haugeland, The University of Chicago Press.

Kuhn, T 1962, *"The Structure of Scientific Revolutions,"* The University of Chicago Press, Chicago, 172p

Kuhn, T 1976, *"Theory-Change as Structure-Change: Comments on the Sneed Formalism,"* Erkenntnis, *(*10)179-199

Kuhn, T; Pittel, K; Schulz, T 2003, *"Recycling for sustainability – a long run perspective,"* International Journal of Global Development (**3**)339-355.

Lundin, R A &Söderholm, A 1995, *"A Theory of Temporary Organization,"* Scandinavian Journal of Management, 11(**4**)437-455.

Lundin, R A & Steinthórsson, R S 2003, *"Studying Organizations as Temporary,"* Scandinavian Journal of Management, 19,233-250.

McLoughlin, I 1999, *"Creative Technological Change: The Shaping of Technology and Organizations,"* Rutledge, London, 188p.

Mitcham, C 1994, *"Thinking Through Technology: The Path between Engineering and Philosophy,"* The University of Chicago Press, Chicago, 299p.

Miozzo, M& Ivory, C 2000, *"Restructuring in the British Construction Industry: Implications of Recent Changes in Project Management and Technology,"* Technology Analysis and Strategic Management, 12(**4**)

Morris, P W G 1994, *"The Managing of Projects,"* Thomas Telford, London, 358p.

Nam, C H & Tatum, C B 1988, *"Major Characteristics of Constructed Products and Resulting Limitations of Construction Technology,"* Construction Management and

Ogunnaike, B & Ray, H W 1995, *"Process Dynamics, Modeling and Control,"* Oxford University Press, New York, 1260p.

Papert, S 2000, *"What's the Big Idea? Towards a Pedagogy of Idea Power,"* IBM Systems Journal, 39 (**3/4**)720-729.

Popper, K 1972, *"Objective Knowledge, An Evolutionary Approach,"* Chapter 4, *'On the Theory of the Objective Mind,'* Oxford University Press, New York

Ranta, J 1993, *"On the Dynamics and Evolution of Production Paradigms,"* SITRA 130, Helsinki, 85p.

Riis, J; Mortensen, J; Johansen, J 1992, *"A New Concept for Managing one-of-a-kind Production,"* In Hirsh, B., E., and Thoben, K., D., (eds.): *"One- of- a-kind Production: New Approaches,"* Elsevier, Amsterdam, pp 195-208.

Santos, A dos, 1999, "*Application of flow principles in the production management of construction sites,"* PhD Thesis, School of Construction and Property Management, University of Salford, 463 p

Shewhart, W A 1931, *"Economic Control of Quality of Manufactured Product,"* Van Nostrand, New York, 501p.

Shewhart, W & Deming, W E 1939, *"Statistical Method from the Viewpoint of Quality Control,"* The Graduate School, The Department of Agriculture, Washington, 155p

Suh, N P 2001, *"Axiomatic Design: Advances and Applications,"* Oxford University Press, 503p.

Tavistock Institute 1966, *"Independence and Uncertainty – A study of the Building Industry,"* Tavistock Publications, London. 83p.

Tilley, P A & McFallan, S L 2000, *"Design and Documentation Quality Survey, Comparison of Designer's and Contractors' Perspectives,"* CSIRO, Victoria.

Voodijk, J T & Vrijhoef, R 2003, *"Improving Supply Chain Management in Construction; What can be Learned from the Aerospace Industry?"* In Greenwood, D., J., (ed.) *"Proceedings of the Annual ARCOM Conference,* University of Brighton, Brighton, 2(**3**)837-846.

Weick, K E 1994, *"Small Wins: Redefining the Scale of Social Problems,"* American Psychologist, 39 (**1**)40-49.

Whetten, D A 1989, *"What Constitutes a Theoretical Contribution?"* Academy of Management Review, 14(**4**)490-495

Wiest, J D & Levy, F K 1969, *"A Management Guide to PERT/CPM,"* Prentice-Hall, Englewood Cliffs. 170p.

Wortmann, J C 1992, *"Production Management Systems for one-of-a-kind Products,"* Computers in Industry, 19(**1**)79-88.

Wortmann, J C; Muntslag, D R; Timmermans, P J M 1997, *"Customer Driven Manufacturing,"* Chapman & Hall, London.