

THE SELF-DESTRUCTION AND RENEWAL OF LEAN CONSTRUCTION THEORY: A PREDICTION FROM BOYD'S THEORY

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ABSTRACT

In 1992, Lauri Koskela used the ideal production system embodied in the Toyota Production System to develop a more overarching production management paradigm for project-based production systems where production is conceptualized in three complementary ways, namely, as a Transformation (T), as a Flow(F), and as Value generation(V). In 2002, Koskela and Howell have presented a new conceptualization of Project Management theory to address the shortcomings in existing planning, execution, and control paradigms as manifested in project-based production systems. This paper introduces and explores Boyd's theory of "Destruction and Creation", which is subsequently used to trace how the Lean Construction underlying theoretical foundation, as represented by the TFV theory of production and the new Project Management theory, was conceived. Boyd's theory also reveals that the more the two theories are used to explain, predict, and control observed reality, i.e., project-based production environments, the more they will fail to match-up with observed reality signaling the need for new theories. Hence, sooner or later the TFV and the new Project Management theories will self-destruct and the chaos created by the inability to match the theories' constructs with observations will result in yet another broader theory of project-based production systems. Evidence exists of this already taking place with the new representation of the construction industry as a complex and chaotic system.

KEY WORDS

Lean Construction Theory, TVF Production Theory

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INTRODUCTION

Around the early 1950s, under the leadership of the brilliant engineer Taichi Ohno, Lean Production principles were developed and successfully implemented by Toyota Motor Company. The minimization of waste in a production system is one of the cornerstones of Lean Production. For example, excess inventories, unnecessary process steps, and idle workers are all examples of waste. Popularized by the book *The Machine That Changed The World* (Womack et al. 1990), these lean principles are being increasingly employed in many other industrial sectors (Womack and Jones 1996).

Koskela's seminal 1992 report argued for the need of a production management theory in construction and presented the TFV theory of production wherein production was conceptualized in three complementary ways, namely, as Transformation, as Flow, and as Value generation. This tripartite view of production has led to the birth of Lean Construction as a discipline that subsumes the transformation-dominated contemporary construction management (Koskela 1999, Koskela 2000, and Bertelsen and Koskela 2002).

Guided by the TFV theory of production, an increasing number of construction academics and professionals are storming the ramparts of conventional construction management in an effort to deliver better value to owners. Lean Construction is now being taught in undergraduate and graduate curriculums by instructors at institutions of higher education around the world (Ballard and Howell 2003). In addition, literature devoted to Lean Construction is now rich with explorations of the TFV theory itself as well as its implementation on project-based production systems, i.e., in construction settings (simple and complex), through the development and successful launching of TFV-based methods and tools.

In 2002, Koskela and Howell presented a new conceptualization of Project Management theory wherein they demonstrated the shortcomings in existing planning, execution, and control paradigms as advocated by contemporary Project Management theory and argued that its constructs are insufficient to manage project-based production systems – that it was in fact obsolete (Koskela and Howell 2002). It was suggested that planning-as-organizing, the action/language perspective, and the scientific experimentation model were critically needed elements to make Project Management theory more robust and contemporaneous. This new conceptualization also confirmed the sound foundation on which Lean Construction theory and practice were based. Further exploration of this new management theory is beyond the scope of this paper and unfamiliar readers are encouraged to peruse the original reference.

According to the criteria discussed by the eminent science philosopher and historian Thomas Kuhn (Kuhn 1970), the rise of the Lean Construction community, defined by its allegiance to a single paradigm², marks the beginnings of a scientific revolution³. In his most popular and renowned work, *The Structure of Scientific Revolutions* (Kuhn 1970), which sold

² Kuhn considered paradigms essential to scientific inquiry and defined a paradigm as a collection of beliefs shared by scientists, a set of agreements about how problems are to be understood.

³ Kuhn defined science as being "a series of peaceful interludes punctuated by intellectually violent revolutions", which he described as "the tradition-shattering complements to the tradition-bound activity of normal science."

some one million copies in 16 languages and is required reading in many science education curriculums, Kuhn observed that during the pursuit of scientific revolutions, "novelty emerges only with difficulty, manifested by resistance, against a background provided by expectation." Kuhn attributed the reluctance and resistance of scientists to new paradigms to the overriding desire to bring the existing theory (paradigm) and observed reality into closer agreement.

History is full of accounts confirming such tendencies. For example, for centuries, the notion that the sun revolved around the earth, which was popularized by Claudius Ptolemy (circa 140 AD), was upheld and defended despite the presence of contrary evidence. It wasn't until the 14th and 15th century with the work of Copernicus, Brahe, Kepler, and Galileo that Ptolemy's synthesis of the universe lost its intellectual appeal and coherence (Spinney 1997). This same work was the inspiration for Newtonian physics which was conceived in the 17th century. This time, scientists embarked on a 200 year of observations and experimentations to match observed reality with the constructs put forth by Sir Isaac Newton. It wasn't until the 19th century when the famous Michelson-Morely experiment found a misfit between observed reality and the predictions of Newtonian physics. This inconsistency was resolved by Albert Einstein's *Special Theory of Relativity*. The rest is history!

Kuhn suggested that a scientific revolution is followed by a paradigm shift wherein "one conceptual world view is replaced by another" and "a scientist's world is qualitatively transformed [and] quantitatively enriched by fundamental novelties of either fact or theory." Kuhn also argued that the new paradigm(s) can only supplant preceding one(s) because "the normal-scientific tradition that emerges from a scientific revolution is not only incompatible but actually incommensurable with that which has gone before." However, Kuhn stated that scientific revolutions come only after long periods of tradition-bound normal science, for "frameworks must be lived with and explored before they can be broken." (Kuhn 1970). Moreover, Kuhn argued that emerging fields of science reach maturity through a process of successive revolutionary transitions from one paradigm to another.

The only known work, at least as confirmed by multiple sources (Spinney 1997, Coram 2003, and Hammond 2001), that provided a theoretical underpinning for why mental constructs (paradigms or theories) of observed reality will be inevitably replaced according to the evolutionary and revolutionary process espoused by Kuhn, is that advanced by John Boyd⁴ in a 1976 paper titled "Destruction and Creation" – Boyd is also the creator of the now-famous "OODA Loop" (Observation, Orientation, Decision, Action) used in both the military and civilian worlds to plan for and accomplish strategic essentials and competitive advantage (Wyly 1991, Richards 2002a and 2002b, Stalk and Hout 2003).

While a comprehensive review of Kuhn's work will provide evidence and confirmation that the Lean Construction community has in fact initiated a scientific revolution in the Construction Management arena⁵, this paper is concerned with applying Boyd's theory of "Destruction and Creation" to show the richness and robustness of the foundation of Lean

⁴ The life of the late Colonel John R. Boyd (USAF Ret) is in-and-of-itself a fascinating and captivating story of a man of uncompromising integrity, intense intelligence, contagious enthusiasm, and a genuine unparalleled commitment to 'do something' instead of 'being someone'

⁵ See Ballard and Howell (2003) for more "Kuhnian" discussions of Lean Construction

Construction – the TFV theory and the new Project Management theory. Boyd's theory also informs us that both theories will inevitably self-destruct and become obsolete and will be replaced with newer theories that can better explain observed reality. The fashion in which this will likely happen is also captured by Boyd's theory.

To this end, the paper begins with a brief discussion of the theory developed by Boyd to explain how the mind manipulates existing knowledge when a mismatch occurs between reality and its governing theory in order to create new knowledge and theoretical models to ameliorate the mismatch. The paper also briefly presents how Boyd proved that existing paradigms and theories will inevitably be made obsolete through new observations that are manipulated and synthesized into new theories – what Boyd called the “never-ending cycle of destruction and creation” (Boyd 1976 and Spinney 1997).

BOYD'S THEORY

In a 1976 16-page double-spaced, type-written paper entitled "Destruction and Creation", Boyd outlined the most elegant and deceptively humble abstraction of how our mental constructs of the external world are inevitably destroyed and created through a 'dialectic' activity. The following is the abstract of the paper as originally written by Boyd:

“To comprehend and cope with our environment we develop mental patterns or concepts of meaning. The purpose of this paper is to sketch out how we destroy and create these patterns to permit us to both shape and be shaped by a changing environment. In this sense, the discussion also literally shows why we cannot avoid this kind of activity if we intend to survive on our own terms. The activity is dialectic in nature generating both disorder and order that emerges as a changing and expanding universe of mental concepts matched to a changing and expanding universe of observed reality.” (Boyd 1976).

In explaining how we arrive at mental concepts of meaning that we associate with the realities observed in the world around us, Boyd stated that we may choose to breakdown a whole to its particulars, i.e., going from general-to-specific, or we may construct a whole from its particulars, i.e., going from specific-to-general. The former is achieved through deduction, analysis, and differentiation, whereas the latter is achieved by induction, synthesis, and integration (Boyd 1976).

Spinney (1997) used a 'pyramid' (Figure 1) to illustrate the interplay between these two opposite processes in a single domain – Boyd used the word domain to represent a comprehensive whole. When a pyramid (think of one of the great pyramids in Egypt) is encountered for the first time, in order to understand it we first dissect it to different perspectives, similar to those shown in Figure 1. Then we embark on analyzing each perspective until we eventually combine them to construct a mental concept of the pyramid. Note that during the planning of construction projects, a similar dialectic process is used when a structure is broken down to its constituent parts and then the parts are sequenced to arrive at the general order in which the construction will take place – In conventional Construction Management this is the Work Breakdown Structure.

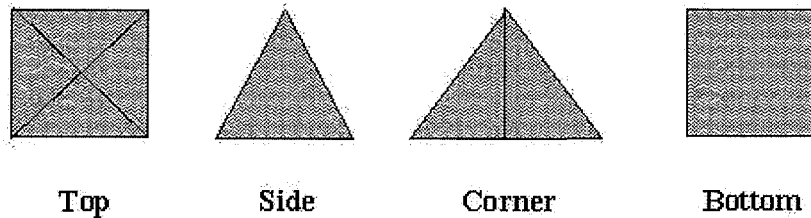


Figure 1. A pyramid viewed in different perspectives (Spinney 1997)

According to Boyd, while the interplay between deduction and induction provides more insight into an existing domain (the pyramid, the constructed facility, etc), new and creative domains will only result if deduction and induction are applied across multiple existing domains. For example, consider the domains shown in Figure 2, which have been used as a classical example to explain Boyd’s ‘dialectic engine’ idea (Spinney 1997, Coram 2003). In this case, the process of deduction is used to ‘shatter’ all the interrelations within each domain. The result are constituent parts that are “swimming around in a sea of anarchy” (Boyd 1976) – see Figure 3. This dismantling of constituent parts over multiple domains is what Boyd termed as a *destructive deduction*.

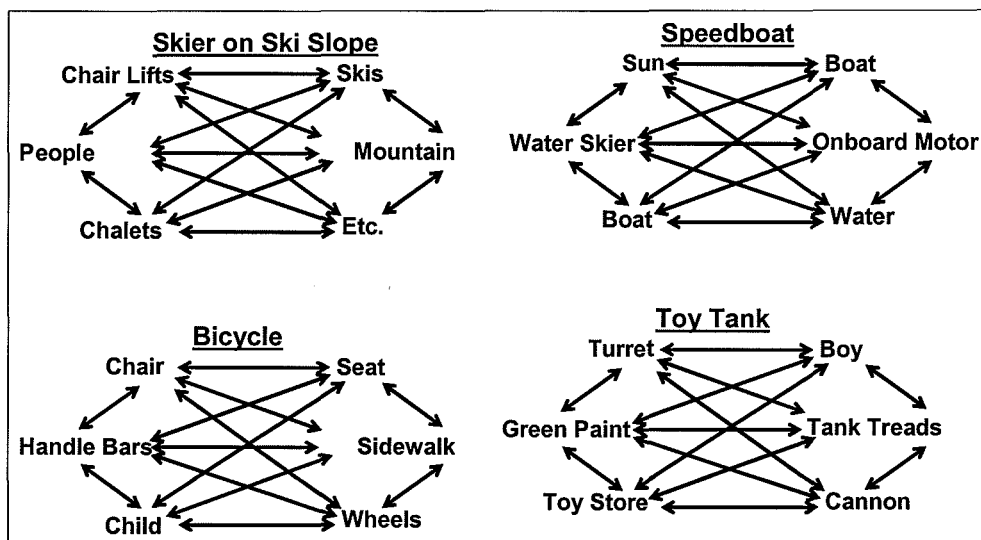


Figure 2. Example of multiple domains (Spinney 1997)

The disorder and chaos created by *destructive deduction*, as shown in Figure 3, is countered by *creative induction*. In this process, we seek out novel combinations using the constituents that are swimming in the sea of anarchy. Eventually, a new and novel domain will be established (see Figure 4a and 4b). Before accepting this new domain as such, Boyd observes that we engage in internal consistency validation wherein the constituents of the new domain must go together without contradictions and the new domain itself must match-up with reality (Boyd 1976). Contradiction or mismatches with reality takes us back through

the same cycle of destructive deduction and creative induction. Once the new domain is accepted as the basis to alter and change our perceptions of reality, Boyd states, similar to Kuhn's position, that:

"The effort is turned inward towards fine tuning the ideas and interactions in order to improve generality and produce a more precise match of the conceptual pattern with reality. Toward this end, the concept—and its internal workings—is tested and compared against observed phenomena over and over again in many different and subtle ways." (Boyd 1976).

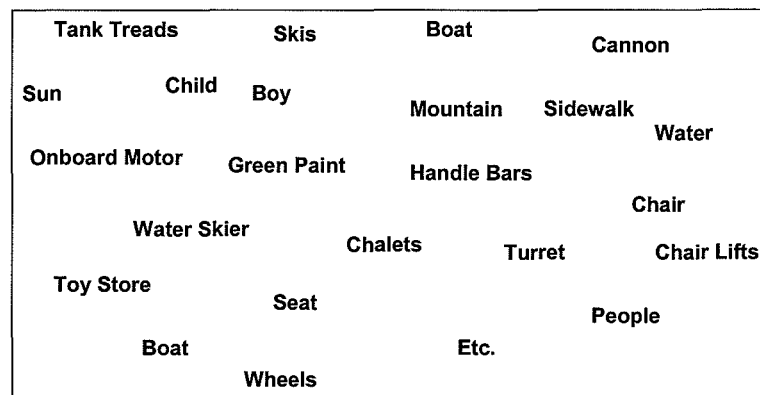


Figure 3. The constituent parts of the shattered domains (Spinney 1997)

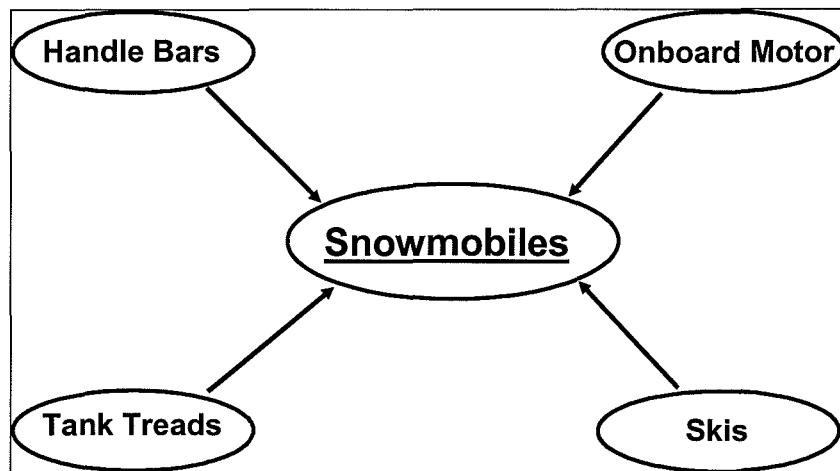


Figure 4a. A new domain results when using *creative induction* (Spinney 1997).

Referring to Kuhn's views on how science progresses over time, Boyd suggested that the increasing use of the new domain or orientation in reconciling more complex and subtle observations of reality will eventually result in inconsistencies and mismatches. This will trigger the cycle of *destructive deduction* and *creative induction* so that we can move from

chaos and disorder back to organization and order. Boyd then set out to prove that the cycle of *destructive deduction* and *creative induction* will inevitably repeat as a result of eventual mismatches between observations and theories, paradigms, principles, etc. It is this proof that completes his elegant theory of “Destruction and Creativity”. Due to space limitations a comprehensive discussion of all aspects of Boyd’s proof and theory will not be presented. The reader is encouraged to consult the original unpublished⁶ paper by Boyd.

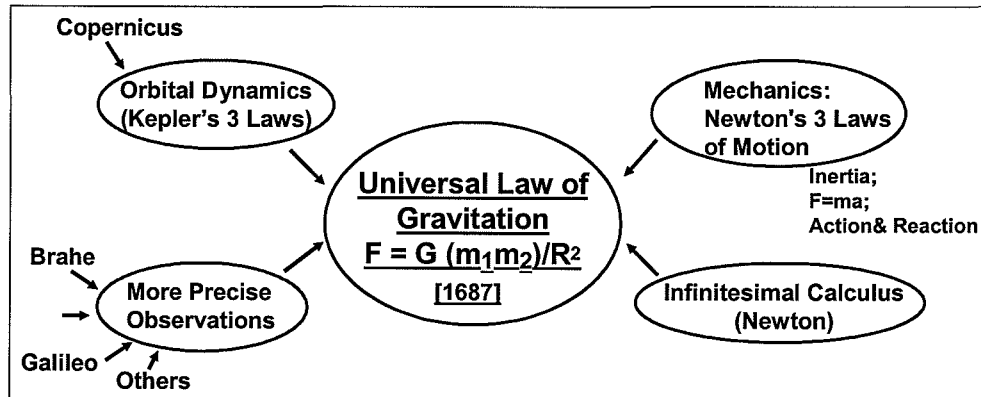


Figure 4b. The result of Newton’s *creative induction* (Spinney 1997).

In proving that we should always anticipate a mismatch between observed phenomena and theoretical description of these phenomena, Boyd created a new ‘snowmobile’ by synthesizing and aggregating for the first time Kurt Gödel’s Incompleteness Theorem of Mathematics, physicist Werner Heisenberg’s Uncertainty Principle, and finally the Second Law of Thermodynamics. Each of these theorems will be briefly explained as Boyd interpreted them followed by his ingenious aggregation.

GÖDEL’S INCOMPLETENESS THEOREM

Gödel’s 1931 Incompleteness Theorem of Mathematics states that:

“Any logical system which includes at least ordinary arithmetic can express true assertions which nevertheless cannot be deduced from its axioms. Furthermore, the axioms in such a system with or without additional truths cannot be shown in advance to be free from hidden contradictions. In short, a logical system which has any richness can never be complete, yet cannot be guaranteed to be consistent.....it is impossible to embrace mathematics within a single system of logic” (Morgan 2004).

Jones and Wilson (1995) give more explanation of Gödel’s work by stating that:

⁶ In describing this particular paper by Boyd, Spinney (1997) stated that “Typically, he [Boyd] did not even try to publish his paper, although he did vet it through many distinguished scientists and mathematicians — none of whom was able to poke any holes in it.”

“The implication [of Gödel Theorem] is that all logical systems of any complexity are, by definition, incomplete; each of them contains, at any given time, more true statements than it can possibly prove according to its own defining set of rules.”

Gödel's Theorem has been the basis for suggesting that humans will not be outsmarted by computers because the latter's knowledge is limited by a fixed set of axioms while that of human's is continuously changing. It has also been suggested that Gödel's Theorem explains “why computer systems that are not severely restricted in scope (e.g.,MRP/ERP) tend to be incomplete and inconsistent” (Morgan 2004). Perhaps the most provocative implication of Gödel's Theorem is that a person will never be able to understand himself or herself because one's mind “can only be sure of what it knows about itself by relying on what it knows about itself” Jones and Wilson (1995).

In his own work, Boyd (1976) stated that the results of Gödel's theory reveal that “any consistent system of axioms contains statements or concepts that cannot be deduced from the postulates that make-up the system”. Boyd further extended this to mean that system consistency – *in terms of its concept, and match-up with observed reality* – cannot be demonstrated within the system, even if the system itself is known to be consistent. However, system consistency can be proved by appealing to systems external to that under study. Boyd stated this as follows:

“Gödel's Proof indirectly shows that in order to determine the consistency of any new system we must construct or uncover another system beyond it. Over and over this cycle must be repeated to determine the consistency of more and more elaborate systems.” (Boyd 1976).

HEISENBERG'S INDETERMINACY PRINCIPLE

The Indeterminacy Principle, frequently cited as the “Uncertainty Principle” was uncovered by Werner Heisenberg in 1927. This principle states that “The more precisely the position is determined, the less precisely the momentum [or velocity] is known in this instant, and vice versa” (American Institute of Physics and Cassidy 2004), i.e., the position and momentum (velocity) of a particle or body cannot be simultaneously and precisely determined. Heisenberg also showed that the higher the observation accuracy required, the more the uncertainty values will hide or mask the phenomena being observed. In other words, the observer will be observing uncertain and erratic behavior. The opposite of course is true, and Boyd stated that:

“Under these circumstances [those of measuring particle position and momentum], the uncertainty values represent the inability to determine the character or nature (consistency) of a system within itself [and] represent the degree of intrusion by the observer upon the observed...[as well as] .the degree of confusion and disorder perceived by that observer” (Boyd (1976).

ENTROPY – THE SECOND LAW OF THERMODYNAMICS

The final piece that Boyd integrates into his new orientation is the Second Law of Thermodynamics. The typical definition of this law states that “the entropy of the universe

increases during any spontaneous process.” A less confusing definition is that “Energy spontaneously disperses from being localized to becoming spread out if it is not hindered.” (Lambert 2004). Entropy is a concept that represents the potential for doing work – it is essentially a measure of the spontaneous release of energy. High (low) entropy indicates a lower (higher) potential and efficiency for doing work.

Boyd adds to this definition that entropy also reflects the “degree of confusion and disorder associated with any physical or information activity...[and that] high entropy [reflects a]...high degree of confusion and disorder”. Because all observed natural processes generate entropy, the level of confusion and disorder will increase in a system that is not interacting in an orderly fashion with systems or environments external to it. Consequently, Boyd observed that:

“Whenever we attempt to do work or take action inside such a system—a concept and its match-up with reality—we should anticipate an increase in entropy, and, hence, an increase in confusion and disorder. Naturally, this means we cannot determine the character or nature (consistency) of such a system within itself, because the system is moving irreversibly toward a higher, yet unknown, state of confusion and disorder.” (Boyd 1976).

BOYD’S SNOWMOBILE

Boyd aggregated these ideas and stated his theory as follows:

“Any inward-oriented and continued effort to improve the match-up of concept with observed reality will only increase the degree of mismatch”.

The mismatch Boyd refers to will give rise to uncertainty and disorder about the nature of the system being observed. This state of confusion will continue to increase until new concepts and/or paradigms are formed through the process of destructive deduction and creative induction carried out in a dialectic fashion. Arriving at newer, boarder, and more general mental models to represent reality will bring back a state of stability and order as well as marking the beginning of a new cycle of inward-looking.

Spinney (1997) depicted Boyd’s theory as shown in Figure 5 implying that the same destructive deduction and creative induction was what enabled Boyd to arrive at this new ‘snowmobile’. While Boyd’s theory may appear parsimonious for a grand theory, it is exactly that feature that makes it so elegantly descriptive and insightful about pursuits of novel and creative discovery.

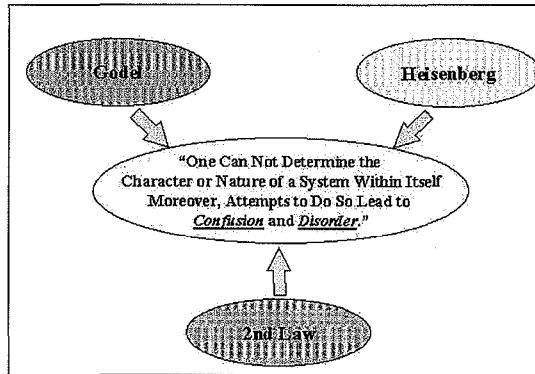


Figure 5. Boyd's Snowmobile (Spinney 1997)

NEW PRODUCTION AND PROJECT MANAGEMENT SNOWMOBILES

The failure and inability of the conceptual models of construction management to deliver on the mantra of 'on-time, at budget, and at desired quality' is discussed at length in Koskela's seminal 1992 report and in Koskela (2000). This failure was evident from empirical data indicating that construction projects were low efficiency systems as manifested by endemic quality problems and rising litigation. Another paradigm-breaking anomaly was that observed by Ballard (1994), Ballard and Howell (1994a and 1994b), Howell and Ballard (1994a and 1994b) and Howell (1998). Analysis of project plan failures were indicated that "normally only about 50% of the tasks on weekly work plans are completed by the end of the plan week" and that most of the problems were possible to mitigate by contractors through an "active management of variability, starting with the structuring of the project (temporary production system) and continuing through its operation and improvement." (Ballard and Howell 2003).

Koskela argued that the mismatch between the conceptual models and observed reality underscored the lack of robustness in the existing constructs and signaled the need for a theory of production in construction. Koskela and Howell (2002) have also presented a comprehensive review of the shortcomings existing management theory – specifically as related to the planning, execution, and control paradigms – in project-based production systems.

As predicted by Boyd's theory, when the failures and mismatches in both the Production and Project Management paradigms used in construction were probed further and inwardly more disorder and confusion followed. The stability and order began to appear as a result of an outward-oriented search into the production paradigms that dominated and competed in the manufacturing industries, namely, craft, mass and lean production paradigms. Koskela then used the ideal production system embodied in the Toyota Production System to develop a more overarching production management paradigm for project-based production systems where production is conceptualized in three complementary ways, namely, as a Transformation (T), as a Flow(F), and as Value generation(V). A similar process resulted in the new Project Management theory introduced by Koskela and Howell (2002). Both

conceptualizations provide a solid intellectual foundation of Lean Construction as evident from both research and practice.

THE TFV THEORY AND BOYD'S THEORY

Boyd's "Destruction and Creation" theory may be used to show that in developing the Transformation-Flow-Value (TFV) theory, Koskela integrated the efficacious qualities of Craft, Mass, and Lean Production paradigms, as well as the inclusion of the value management perspective. Through a process of destructive deduction, Koskela analyzed (dismantled) each production paradigm to understand its historical and scientific origins, governing characteristics and attributes, as well as associated advantages and disadvantages as implied by realized industrial models (e.g., Ford in the case of mass and Toyota in the case of Lean). Then, by shattering the linkages among the elements within each paradigm and considering the resulting chaos, a creative induction process followed wherein the TFV theory was conceived as a novel combination from the many configurations which were possible. Specifically, craft production embodied the transformation view, while mass and lean production embodied the flow view, whereas the view that production is also a process of value creation and generation was inspired by the over-reliance on the transformation and flow paradigms. The inclusion of value generation is a unique feature of the TFV theory and makes it more robust and broader conceptualization than just the ideal production system embodied in the Toyota Production System. This process of "Destruction and Creation" resulted in Koskela's Production 'snowmobile' and is depicted in Figure 6.

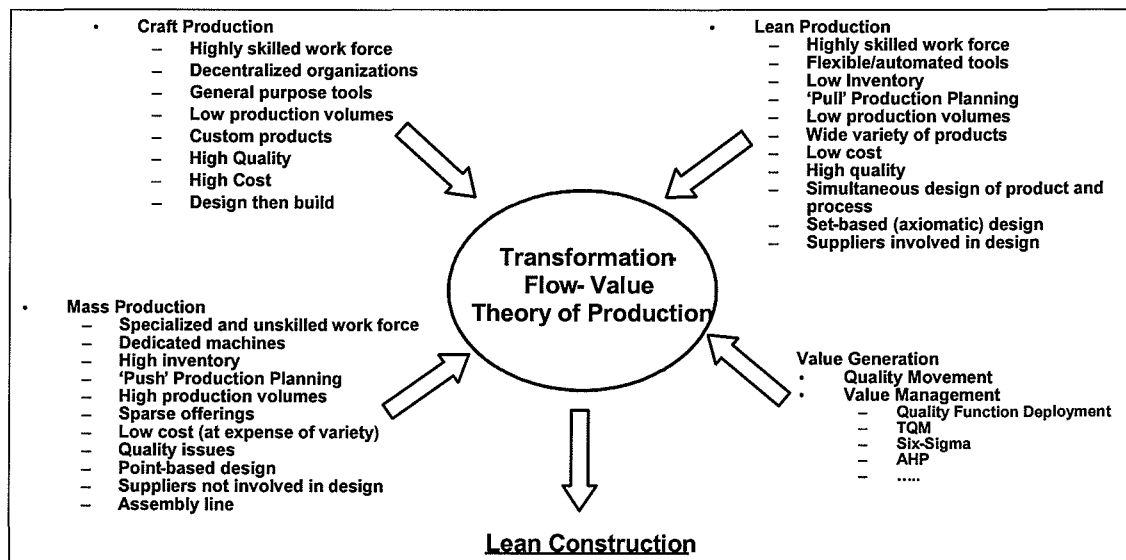


Figure 6. Koskela's Production 'Snowmobile'

THE NEW PROJECT MANAGEMENT THEORY AND BOYD’S THEORY

Due to lack of space, the application of Boyd’s “Destruction and Creation” to the new Project Management theory conceptualization by Koskela and Howell (2002) will not be discussed at length. The following excerpts from the original paper by Koskela and Howell (2002) reflect the essence of the findings and recommendations made:

“The deficiencies of the theory of the project and of the theory of management reinforce each other and their detrimental effects propagate through the life cycle of a project.....We have put forward empirical evidence and theoretical explanation, which suggest that the present doctrine of project management suffers from serious deficiencies in its theoretical base. Firstly, it rests on a faulty understanding of the nature of work in projects, and deficient definitions of planning, execution and control. Secondly, the theoretical base has been implicit..”

It is now hopefully apparent that a destructive deduction process followed by a creative induction process is what led Koskela and Howell (2002) to suggest that the existing constructs of management theory, namely, planning, execution, and control, were deficient for managing project-based production systems. Figure 7 illustrates this new Project Management theory as a new ‘snowmobile’.

Superimposing Figure 6 and 7, as shown in Figure 8, depicts Lean Construction in terms of the new production and management theories and completes the entire façade of new paradigms that will govern Lean Construction research and practice for years to come.

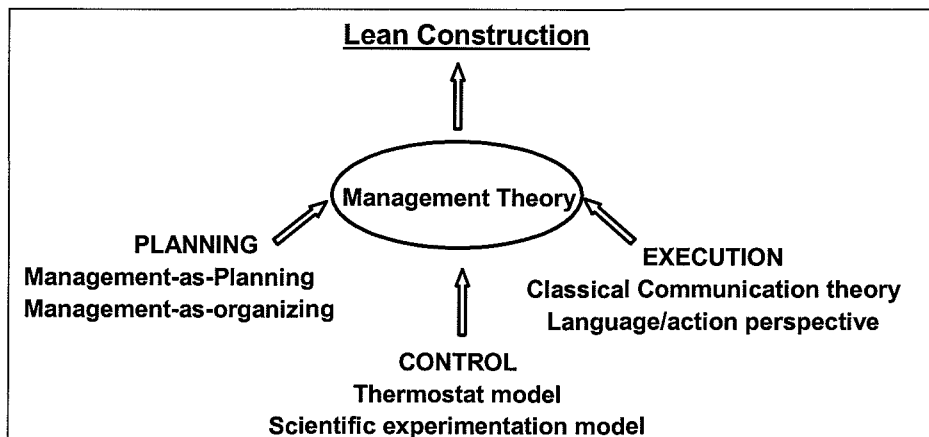


Figure 7. Koskela and Howell new Project Management ‘snowmobile’

SELF-DESTRUCTION AND RENEWAL OF LEAN CONSTRUCTION

To counter the disorder and chaos created by the mismatch between existing paradigms and observed reality as well as that created by destructive deduction of the ramparts of known production paradigms, using creative induction Koskela found a novel combination and presented the TFV theory of production. The same process resulted in a new management

conceptualization as discussed in Koskela and Howell (2002). Since 1992, an increasing number of academics and practitioners have been subjecting the constructs of these new paradigms to the internal consistency validation process as described by Boyd. To date, the evidence collected through numerous studies conducted by the Lean Construction community overwhelmingly points to a satisfactory match-up between the paradigms and observed reality.

As the new paradigms gain more acceptances and achieve full penetration in academia and industry, the growing Lean Construction community will focus its efforts on *solidifying and honing* the match-up between the TFV and Project Management theory and observed reality. And as aptly stated by Boyd (1976): “Toward this end, the concept—and its internal workings—is tested and compared against observed phenomena over and over again in many different and subtle ways.”

However, Boyd’s theory reveals that the increasing utilization of the TFV and Project Management theory to explain, predict, and control observed reality, i.e., construction project and production environments, will eventually lead us to situations where the theories fail to match-up with observed reality – signaling the need for a modification or renewal of theory. Hence, sooner or later both theories will self-destruct and the chaos created by the inability to match its constructs with observations will result in yet another broader theory of Production and of Project Management. Again, we will arrive at these new theories through Boyd’s dialectic engine of destructive deduction and creative induction.

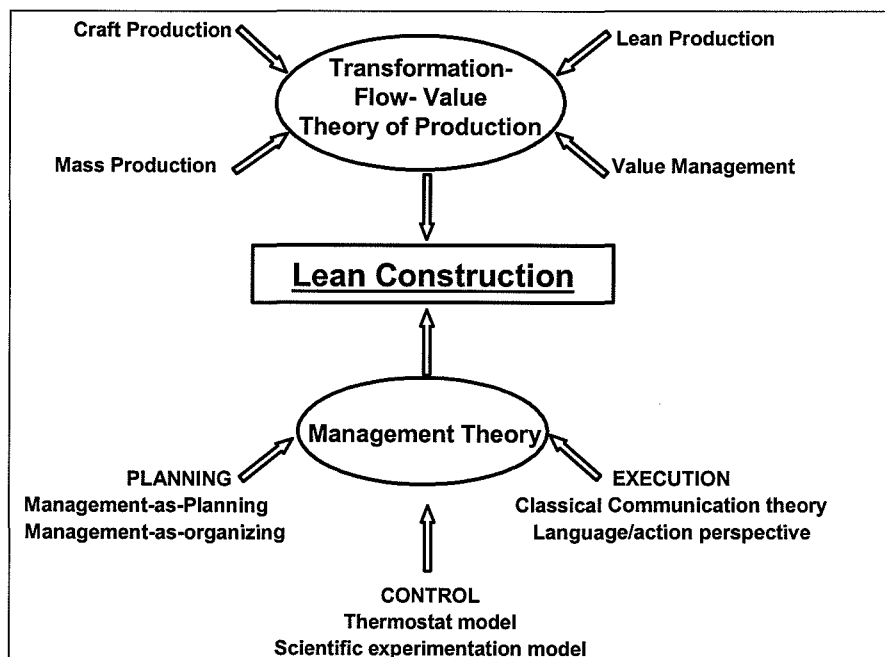


Figure 8. The Lean Construction ‘Snowmobile’

COMPLEXITY VIEW – BOYD’S THEORY IN ACTION

The self-destruction and renewal of the two paradigms governing Lean Construction appears to be already happening. Recognizing that construction sites reflect prototypical behavior of complex and chaotic systems, especially in the flow of both material and information on and off site, Bertelsen⁷ (2003a and 2003b) suggested that construction should be modeled using chaos and complex systems theory. A brief summary of the two is in order before presenting Bertelsen’s competing conceptualization of Lean Construction.

Chaos theory states that precise prediction of the behavior of complex systems will be impossible at particular times but that repeated patterns and trends can be discovered and used despite the chaotic nature of the system (Gleick 1987 and Lorenz 1993) – a close cousin of Gödel’s Theorem. Hence, we have to be realistic about our expectations from prevailing theories in that we will find limitations as we investigate different aspects of project-based production systems. Instead of attributing these limitations to incidental aberrations, we should study them carefully and intensely. On the other hand, Complexity or complex systems have escaped canonical definition primarily because any system is inherently complex at some level. Bertelsen (2003b) states that “complex systems are not a special class of systems but a way of looking upon any system as opposite to the ordered viewpoint, which has dominated the Western science’s reductionistic approach since the Renaissance.” This calls for the investigation of systems as a whole and the interactions between its constituents as intently as we investigate the constituents in isolation.

Bertelsen (2003b) specifically argues that construction could and should be understood in three complimentary ways, namely, as a project-based production process similar to Koskela and Howell’s ‘snowmobiles’, as an *industry that provides autonomous agents*, and as a *social system*. This conceptualization is depicted as shown in Figure 9. The work of Bertelsen provides a case in point regarding the dynamics Boyd captured in his theory regarding the evolution of knowledge. With more developments in this line of thinking, it is very likely that the Lean Construction governing paradigm will change to it. And so, the process will keep on repeating!

⁷ In an email exchange on the *Planner2Planner* e-community (yahoo! group), Sven Bertelsen (April 6th, 2004) aptly stated that a construction production environment gives rise to *turbulent* flows while a manufacturing environment is more conducive to *laminar* flows.

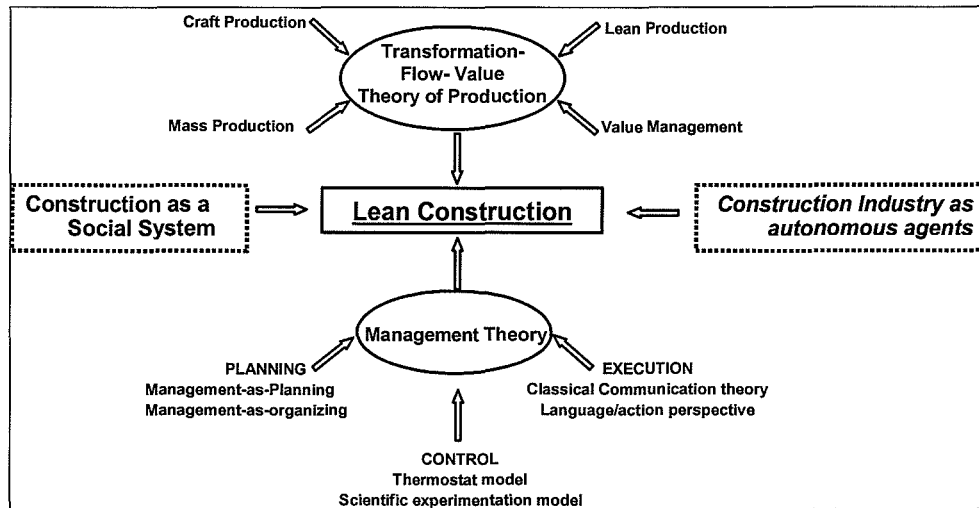


Figure 9. Possible future of the Lean Construction ‘Snowmobile’ based on Bertelsen (2003a and 2003b)

It is important to note that many authors have suggested the use of complexity theory in construction (Cox and Goodman 1956, Winch 1987, Kreiner 1995, Gidado 1996, and Shirazi et al 1996, Dubios and Gadde 2002). However, these prior references and uses of complexity focused primarily on the characterization of the organizational structure of the construction industry and its supply chain as well as that of the construction site. While useful, this characterization was not used to synthesize a competing paradigm to conventional project planning and control practices. Rather, it was used to seek and inform improvements of practices under existing paradigm. Bertelsen’s work cited above is different in that it aims to improve the Lean Construction paradigm itself.

GÖDEL, HEISENBERG, AND ENTROPY IN CONSTRUCTION

Other striking insights worth mentioning about the nature of the construction industry are revealed by the three separate Theorems that Boyd used to arrive at his “Destruction and Creation” Theorem. Consider for example the typical, but now overrated, argument of individuals who hear of Lean Construction for the first-time, which is that construction is not manufacturing and therefore the imposition of Lean Production in construction environments is a *waste of time!* Gödel’s Theorem indicates that even if we derive our *unique* set of axioms from *within* construction, we will always fall short of finding a complete and consistent set of axioms. We must therefore look *outside* our construction environment for practices and innovations from other industries to edge closer to completeness, recognizing, as Lean Construction advocates have, that blind imposition without thoughtful tailoring is a recipe for failure and disaster. In general, we should expand this to mean that we must look for insights and direction both *inside* and *outside* the system we are seeking to improve.

The ubiquitous use of CPM-based scheduling software for planning, execution, and control of production on construction projects is frequently cited by Lean Construction advocates as a problem with current Construction Management practice (Ballard and Howell 2003). Again, Gödel's Theorem informs us that the *non-restricted* use of CPM scheduling software inevitably results in incomplete and inconsistent outcomes. This validates the recommendation of the Lean Construction community to use CPM-based software in a *restricted* manner, namely, to create Master and Phase-level schedules, whereas production execution and control should be managed using the Last Planner System (Ballard and Howell 1994a, 1994b, and 1998, Ballard 1997 and 2000).

Recall that Heisenberg's Indeterminacy Principle states that: "The more precisely the position is determined, the less precisely the momentum is known in this instant, and vice versa". It may be argued that 'position' is similar to project 'status' and 'momentum' is similar to 'throughput' of a project. Hence, Heisenberg's principle indicates that the conventional construction management practice of measuring the overall timeliness and budgetary status (position) of a project using schedule/cost variances will result in a less precise assessment of the throughput (momentum) of the project.

Consider now that 'position' and 'status' both reflect a static state, whereas 'momentum' and 'throughput' both reflect a dynamic state and will inform prediction on future position/status. Clearly, from a project management standpoint we should be more interested in directing our energies and resources in measuring 'throughput' and not 'status' because we care more about where the project is headed – as apposed to studying particles at the atomic or sub-atomic level where the simultaneous determination of position (status) and momentum (throughput) is desired. This supports Lean Construction practices focusing on the use of the Last Planner System to measure and improve percent plan complete (PPC) which reflects production planning effectiveness *and* workflow reliability, which in turn reflects system throughput – the higher the PPC, the higher the production planning effectiveness *and* workflow reliability, and the higher the throughput.

It is also important to note that Boyd's definition of entropy as the "degree of confusion and disorder associated with any physical or information activity" also inspires the characterization of construction environments as complex and chaotic. Specifically, it follows from the definition that construction production environments are *high entropy* environments which give rise to high degree of confusion and disorder. In other words, construction projects are high *entropy* systems, i.e., low efficiency systems characterized by high input and low output. Consequently, to reduce the level of confusion and disorder the construction project must interact in an orderly fashion with systems or environments external to it. Lean Construction, with its emphasis on work structuring (alignment of product and process design and supply chains) to improve production unit performance and workflow reliability, provides the framework for achieving such orderly interaction.

CONCLUSION

This paper discussed Boyd's theory of "Destruction and Creation" which elegantly describes a dialectic process of knowledge manipulation and regeneration in order to resolve mismatches between observed reality and mental constructs (theories) as well as articulating why this process is inevitably repeatable– what Boyd called the "never-ending cycle of

destruction and creation” (Boyd 1976). Then, Boyd’s theory was used to demonstrate the richness and robustness of the foundation of Lean Construction as embodied in Koskela’s TFV theory and the new Project Management theory presented by Koskela and Howell (2002). The same theory also predicts that the TFV theory and the new Project Management theory will inevitably self-destruct and become obsolete and will be replaced with newer theories that can better align observed reality to theoretical constructs. Evidence exists of this already taking place with the new representation of the construction industry as a complex system.

Engaging in an exercise where Boyd’s theory is turned on itself, i.e., that Boyd’s theory will itself self-destruct and be replaced with newer theories is perfectly plausible. However, because Boyd’s theory rests on three robustly proven theories, it is unlikely a new and competing theory will be introduced in the near future. Perhaps, this is why Boyd built in some redundancy in his theory. At this time, we are compelled to accept Boyd’s theory and subject it to testing and comparisons against observed reality. At some point, a mismatch will result and a new theory of ‘Destruction and Creation’ will be needed.

Last but not least, separate appeals to Gödel’s Theorem and Heisenberg’s Principle confirm the soundness of Lean Construction practices related to limiting the use of CPM-based schedules to the Master and Phase-level schedules, as well as the implementation of the Last Planner System to improve production planning effectiveness and workflow reliability that ultimately improves throughput. The concept of Entropy provides a provocative metaphor to characterize construction environments as well as indicating that mastery of Lean Construction will result in *laminarizing the turbulent flow* and in an overall *low entropy* (high efficiency) construction system. Gödel’s Theorem also indicates that when seeking to make our processes more efficient we must look both *inside* and *outside* the system for improvement ideas – look outside your site, company, supply chain, profession, and industry. That’s the essence (the Schwerpunkt, to borrow from Boyd) of Lean Construction.

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