Towards a Construction Industry Paradigm

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Abstract:

This paper addresses the need to “know why” we build by looking first at the systemic nature, and complexity, that informs the construction industry’s current paradigm. An objective of this paper is to present how the construction industry’s reigning paradigm is driven by an entrenched and obfuscating manufacturing-industrial-engineering mindset.

This obfuscation is not abnormal. According to Kuhn (1962), when a paradigm is entrenched for a relatively long period of time, while scientific advances provide an elixir of progress through first time and later technologies (Garcia Bacca 1989), the anomalies are masked until a period of crisis backlights the discontinuities (anomalies) allowing, often grudgingly, a different perspective. In other words, advances in components manufacturing and processes have masked the discontinuity between the concepts of construction as-it-is and manufacturing as-it-is; between construction expectations and manufacturing expectations.

Under the NAICS (North American Industry Classification System of the US Census Bureau), the construction industry is listed in the service sector of the economy under section 23 and is broken down into many categories, such as Buildings (236) and Heavy and Civil (237). Construction is considered a basic industry, like manufacturing, mining, fishing and farming. This industrial classification system implies a scientific-industrial-manufacturing-managing paradigm that is expected to overarch all industries. However, construction fails repeatedly to conform to an industrial paradigm.

For example, Latham (1995) and Egan (1998, 2002) have, over the past ten years, challenged the industry to improve its efficiency as well as the quality of its output. Failure by the industry to achieve these efficiencies points to a lack of understanding of the systemic nature of the industry (Fernandez-Solis 2006).

In order to gain a higher perspective on the anomalies, we enlist philosophical tools. Koskela and Kagioglou (2006), in “The Metaphysics of Production,” take philosophy in construction seriously and search for theoretical foundations and clarity of thought (Hegel 1975).

Keywords:

Metaphysics, Paradigm, Philosophy, Systemic Nature of the Construction-Industry
1. Introduction

The magnitude of the global construction industry is approximately 40% of global GDP. A greater global demand and an accelerating global GDP have created an increase in construction activity—the production of artifacts (immobiles), buildings and infrastructure—at a continually increasing rate of growth. Global GDP is estimated to double within the next 30 years and then double again in less than 30 years! In construction alone, between 2000 and 2030 it is estimated that the global amount of construction assets in place (infrastructure and buildings) at the end of 2000 will double by 2030 (Stern 2006). Current construction trends (Fernandez-Solis 2006) affirm this estimate that initially was considered outrageous.

Considerable effort in construction is dedicated to increasing efficiencies based on improving “know-how,” through Lean Construction (LC), Critical Path Method (CPM, Last Planner System (LPS), Just in Time (JIT) movements among others, experiments using different project delivery systems such as Design-Bid-Build (DBB); Design-Build (DB); Construction Manager at Risk (CM@r) to name a few, and application of technological and informational systems.

A recent addition to the picture of artifact production is an ecological sensitivity to resource consumption and emissions generation. Particularly, emissions generation has been determined by the majority of the scientific community to be a major cause of climate change (Stern 2006; IPCC 2007). Construction (from resource extraction transformation and use) is a major contributor, directly and indirectly, to emissions generation.

Laudable initiatives, which link design to quality of life and introduce metrics for valuation of the Built Environment in terms of sustainable growth that is eco-sensitive, come from a wide variety of national and international governmental and non-governmental organizations. For example: In the UK - CABE, GBTool and nCRISP; in the USA - LEED, BREEAM and ASTM; in the EU - HQE® by CSTB France; at the international level - CIB, the Stern Review Report (2006) and IPCC (2007).

The reigning paradigm dictates that the production of these artifacts should follow industrial trends of increased efficiency, control, quality, productivity and overall decrease in cost per unit as seen in the automobile, shipping, and aerospace industries (Ranta 1993). However, as noted, this trend has not been experienced in construction.

Why? Perhaps the construction industry has been fascinated with the pragmatism of the ‘know-how’ and not ventured enough into the highly theoretical field of the ‘know-why.’ Why this inquiry into a highly theoretical field? Most disciplines, after the advent of the Industrial Revolution, progressively ventured into the
formulation and debate of highly theoretical constructs or insights, long before those concepts were or could be confirmed.

Obvious examples include: Columbus (the earth is round), and Galileo and Copernicus (the earth is not the center of planetary movement). Engineering has multiple disciplines that forayed into the highly theoretical before being proven by experimentation; for example, Faraday’s (1791-1867) intuition about the electricity and magnetism; Maxwell’s (1831-1879) intuitive theories of energy; Lavoisier’s (1743-1794) heuristic concept of mass through chemistry; du Châtelet’s (1706-1749) thoughts about the $v^2$; Roemer’s (1644-1710) intuitive perception of the notion of the speed of light; and Einstein’s originally highly controversial formula $E=mc^2$ where the speed of light is the only constant.

Construction, a most practical ‘brick and mortar’ discipline, is begging for the same freedom to entertain, dream and debate the highly theoretical as a way of probing the universe of possibilities for its uniqueness and for its own paradigm (see Fig. 1). Behind the issue of the freedom to explore lurks a deeper question: Why should all disciplines, except construction, have rich backgrounds in proto-theoretical thinking, in new knowledge, and grand ideas? Is construction to be relegated in the short and long horizons to the craft that simply applies other disciplines’ theories? Can we dare with novel, outside the box, cutting edge thinking?

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<td>Fig. 1 Partial modalities of experience (adapted from Planck as quoted by Garcia Bacca 1963, Heidegger (1954) and Embree 1996)</td>
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2. Methodology: Invoking Philosophy in Construction Thinking

This philosophical search for clarity invokes the following Socratic attitudes: The first is based on the paradox that not knowing allows the possibility of openness to the truth; the second is similar, the tradition of raising “the question” rather than providing “the answer.” Heidegger (1962) was inordinately suspicious of all easy answers or quick solutions, an attitude echoed by this paper.

The amount of global construction that is occurring, and the possibility that these assets will continue exacerbating a critical environmental problem (affecting global security, a term parallel to national security), makes a search for clarity in construction’s paradigm crucial. We need an understanding of the “why” as well as “how” construction occurs. Durbin (1987) agrees that the urgent problems connected with technology require philosophical clarification since “much that has
been written about these problems is inadequate – making it all the more important for serious philosophers to get involved.” And why should philosophers, instead of scientists, and practitioners, get involved? Kuhn (1962) observed that in a pre-paradigm situation, a paradigm shift, or in a crisis, the professions resort to philosophy (Thompson 1993; Titus et al. 1995) for clarity of ideas, then to science and technology for implementation. Whether our industry is in normal science, in a paradigm shift, or in a crisis may be subjective: however, most scientists at least agree that globally we are on the threshold of a planetary crisis (Stern 2006; IPCC 2007) which will affect our industry.

Therefore we delve into the archives of philosophy, using the tools of metaphysics and epistemology to clarify the foundational concepts that inform a pre-paradigmatic state or one where a paradigm shift may be taking place. In our specific case, a clear distinction of the mechanisms and forces of manufacturing vs. building construction is cardinal to understanding the necessity for a construction paradigm shift.

Koskela and Kagioglou (2006), elucidate how philosophy (until recently considered an obscure and antiquated field of knowledge, and according to some, superseded by science and technology) influences worldview (paradigm), which trickles down to science, technology, processes and products (Nightingale 2000). Recently, the study of metaphysics (Doyle 2004), an ancient and venerable branch of philosophy (Hegel 1975) that investigates the fundamental nature of reality, has started to flourish again (Price 1977; Craig 2000; Roochnick 2004; Palmer 2001b, 2004 and others). Therefore, in general terms, we will address, whenever possible or appropriate, the issues, using logic, epistemology, metaphysics, and/or philosophical thinking to establish foundational knowledge concerning our discipline.

3. Two Metaphysical Worldviews: Entities and Becoming

Koskela and Kagioglou’s (2006) research observed that since the pre-Socratic period, there have been two basic metaphysical worldviews. One holds that the substance of things gives them Being, and it sees them as atemporal entities in the world. We will call this Pure Being. The other insists that there are processes (becoming), by which we see intrinsically temporal phenomena. We will call this Process Being. These metaphysical assumptions (static things, being, entities – products; and dynamic, becoming, temporal – processes) strongly influence how any particular inquiry or action is conceptualized.

Entities (the real, the artifact) are viewed as both resources and products. Becoming (the temporal) is the process (transformation, flow and transforming values). The entity and the process can be both an ideal and a real. The gaps between the ideal and real have characteristics such as efficiency, effectiveness, cost, time, and quality
among others. Anomalies can and often do arise between the ideal plan (a projection of Pure Being) and the actual real execution (Process Being, or Becoming), that is between performance targets and actual commissioning.

Correspondingly there are two worldviews: A worldview of the ideal which is “what should be” and a worldview of “what is,” which respectively inform the entity (product) and the becoming of construction (process). A worldview of “what it is,” (the product) embodies the becoming that takes place during construction and endures with the characteristics and attributes embedded into it during the becoming, (the life cycle, emissions generation, resource consumption), as well as other embedded performance, economic and social characteristics and attributes of the product.

Between the worldviews of “what should-be” and “what it is,” the metrics of performance, efficiency, and effectiveness are characterized by change, the “delta” or difference between an original state and a subsequent state. Time is involved the transformation between one and the other. These deltas in what is considered a positive or increasing direction have certain change characteristics.

For example, the worldview of an industry is based on increases in efficiencies that can be gradual, step or radical, thus creating the possibility of creating a taxonomy. Fig. 2 is a change taxonomy derived by Fernandez-Solis (2007b) from Slaughter (2000). Construction as an industry is expected to achieve the efficiencies of other industries, such as aircraft, shipbuilding, and automobile.

![Change Taxonomy](image)

**Incremental** – small (gradual)

**Systemic** – multiple, linked, rapid (step)

**Radical** – (new) breakthrough in science or technology

Fig. 2 Change Taxonomy, Adapted from Slaughter (1998) and Kanter (1983)

The anomalies between the desired efficiencies of construction, when compared with other industries and actual practice, have led to an in-depth examination of the industry (Koskela, 2000, and others), beginning with its peculiarities, characteristics and attributes. These studies delineated the types and amount of anomalies in a construction worldview (which sees construction as an industry), comparing them
with other industries in terms of efficiencies, cost reduction, innovation and lately, theory building.

For example, Koskela (2000), when comparing construction with other industries, identified the peculiarities of construction to be: one of a kind, in situ, by an assembled team that may be different on each project. Bridging the gap between construction and normal manufacturing industry brought forth the characteristics of transformation, flow and value as dominant concepts for management and control. Furthermore, extensive work has been done on the attributes of planning, dispatching and constructing. The gap between manufacturing and normal industrial (other than construction) efficiencies and the lack of efficiencies in building construction industry was attributed to a lack of theory in the industry.

One of the reasons for this anomaly was advanced by Koskela (2002) and Koskela and Vrijhoef (2001), in that the construction industry lacks its own body of theories, a quest that has led us to this International Symposium. This is the point in time where, according to Kuhn (1962), we recognize that the existing paradigm does not fully take into account the peculiarities of “construction” and places the findings in direct contrast with the understanding of the term “industry”. A resolution of this conflict first has to take place at a philosophical level with clarity of concepts and ideas, the symbols and meanings (Popper 1972) that are used to augment a paradigm or worldview (see Fig. 3).

![Fig.3 Pluralism and Popper Thesis of the Three Worlds](image)

4. **Philosophical Understanding of Capacity for Change**

From a pure philosophical perspective, “capacity for change” is succinctly defined using Popper’s (1972) method of analysis: capacity for change is a concept defined with philosophical language, constructed by a subjective mind (see Fig. 4). In Koen’s (2003) all-is-heuristic worldview, “capacity for change” and “change” are
both part of a universal heuristic approach. In Koen’s view no further derivation or definition is needed.

Fig. 4 The concepts of Building Construction and Capacity for Change based on Popper (1972)

5. Historical Basis for Construction’s Paradigm

Aristotle (“Nicomachean Ethics,” 2.1.1103a35) defined the first construction paradigm as: “Human beings become builders by building.” The “verb” and “act” of building takes supremacy and the implicit logic is “change.” Change in the natural environment, with an artificial environment created for anthropomorphic use and exhibiting the qualities of *firmitas, utilitas, venustas* (strong or durable, useful, and beautiful) (Vitruvius, c. 40 BC) implies both a “know-why” and a “know-how.” Behind the verb “to act” is another construct, which Koen (2003) in his all-is-heuristic approach has identified as “change.”

Historically, the esoteric (or more philosophical) “know-why” was relegated to the architect, or engineer. On the other hand, resource transformation, flow, and value, the utilization, the “know-why”, required the builder to pass on from generation to generation the “know-how” things-are-done-as-they-are with an emphasis on the act of building using tools, resources, means and methods. These are subtle but significant emphases, with overlapping boundaries.

However, there is another type of change that concerns us in this paper. Although the issue of how builders change the environment is critical, our concern is to “know why” and “know how” construction changes itself throughout history. Since the industrial revolution, science and technology have become agents of change. Why have some industries experienced gradual, step and radical changes while construction, the beneficiary of many of those advances, continues to mostly be perceived as changing gradually? Why do we experience quantum increases
between resources and technology in other industries (transformation, flow and value) and not in construction?

Heidegger (1954) observes, “The essence of modern technology starts human beings upon the way of THAT revealing through which reality everywhere, more or less distinctly, becomes resource,” resources that can become scarce, requiring greater efficiencies in productivity and process utilization, the reigning paradigm of manufacturing, science and technology. In this quest all the problems, including efficiencies and productivity, are technological problems which require more and more comprehensive technology (Mitcham 1994) until higher levels of complexity with increasingly deleterious results, such as those posed by emissions generation require immediate action. According to Descartes (quoted by Koen 2003), “Situations in life often permit no delay; and when we cannot determine the method which is certainly best, we must follow the one which is probably the best…if the method selected is not indeed a good one, at least the reasons for selecting it are excellent.”

We are in that situation where no delay in action is permitted because of the looming catastrophic consequences, such as continuing to produce artifacts under an existing paradigm, at an exponential rate of growth. The application of “more technology” to “the problems that technology has created” has yielded an atmosphere where the return on the investment of all new technologies fails to achieve the results found in other industries. The construction industry is a laggard when efficiency comparisons are made. However, could it be that construction is something other than an industry and that imported or transferable benchmarks from other industries do not fit because of construction’s innate nature?

If the observed anomalies between the current industrial paradigm of construction and practice, and a critique of the state of the art research in the industry indicate that we are in for a shift in the construction paradigm, what are the criteria for a possible paradigm?

One of the points of concern is that the building industry is at the end of a long line of master-slave relations in the class structure of various disciplines. Science rules over engineering, but architecture and engineering rule over construction. Those who engage in construction, until recently, have been less educated than those in these master disciplines. We would argue for continuity between science, architecture, engineering, and construction. Thus the findings of the philosophy of science apply to construction and engineering just as much as to architecture and science. But construction is inherently fragmented because of the many skills and contractors that are brought together in a single team, to accomplish a particular project that is already architected, engineered, and based on scientific principles already understood. Building construction suffers from being the last in line among these disciplines which are really dependent on each other. Ultimately the problems
of the building construction industry are endemic to the whole food chain of disciplines.

6. The Systemic Nature of the Construction Industry and its Complexity

Two main aspects of a worldview are of particular interest and in need of better definition: one relates to an understanding of the systemic nature of building construction as an “industry” and the other to the “characteristics of complexity.” Furthermore we postulate that the intertwined, dynamic, complex characteristics of building construction (Nam and Tatum 1988) are where we observe a paradoxical co-dependency of product (what is, being, entity, artifact) and process (what should be, becoming).

The complexity of the building industry needs to be better understood so that the mechanisms and forces that create change in the industry can be discerned. Why and how change occurs is central to the argument of the paradigm that informs them. Once these two items, complexity and change are in place we then proceed with pre-paradigmatic, analogue type critical thinking, to construct the rules for a bridge between them. Without a full appreciation and understanding of complexity as a main ingredient of building construction, the inquiry on how construction changes will fall short.

Why? Construction complexities provide the backdrop that allows a glimpse at the meta-systemic nature of construction, how it changes the environment and how it changes in time. How do construction complexities compare with other industries such as aircraft? This question will help illuminate the meta-systemic nature of the construction industry. The concept of meta-system as the inverse dual of the system was first proposed by Palmer (2001). See “Theoretical Approach to the Interaction Between the Meta-system Schemas of the Artificial (Built) Environment and Nature” by Solis, Palmer and Ferris (2007).

6.1. Models from other industries

The models of the aircraft, shipbuilding, automobile and other industries should have been sufficient to manage complexity and the drivers of change if building construction has the characteristic of these mass production industries. However if building construction does not reflect the characteristics of these industries, then a new model is needed.

For example, let us compare the aircraft industry with construction instead of the other way around. In this case, each artifact (airplane) would be constructed for one
client with differing requirements than any other, for one type of specific use (say one route). Although the plane could be constructed out of an existing catalogue of parts, it would be designed and built by a team that came into being just for this purpose. Furthermore the airplane would have to be built or assembled on a site open to the elements. The artifact would be unique, meeting governing requirements and obeying the laws of nature, but a distinct product. Absurd as it may seem in this example; the industry believes that theories and practices from one are translatable to the other. A similar example might be satellite engineering, which builds one of a kind machines that cannot be repaired once launched.

Construction in general does not behave as an “industry,” but more like a “conglomerate of industries,” an “industry of industries,” a “meta-industry” (metasystem) that, according to Palmer (2003, 2004), includes holes, absurdities, inefficiencies, and paradoxes as well as the capacity to invent and innovate. If this is the case, past behavior of specific industries is not directly translatable to the behavior of a meta-industry. This line of generic and structural thinking regarding complexity and the systemic nature of building construction as a meta-industry requires additional foundational work.

6.2. Towards an understanding of the systemic nature of the industry

Koen (1985, 2003) succinctly states that the engineering method under which building construction can be located is based on “change,” utilizing available resources, and is based on some “particular rationality” (albeit heuristic rather than scientific in his view). This rationality is derived from “the state of the art” at that point in time, directed towards a “best or optimum solution,” but always occurring in an “environment of uncertainty.” All types of engineering, science, and philosophy fall under the category of heuristics, according to Koen (2003). Koen proposes the following example of heuristic rationality:

“...[A]t the appropriate point in a project, freeze the design; allocate resources as long as the cost of not knowing exceeds the cost of finding out; allocate sufficient resources to the weak link; and solve problems by successive approximation.”

The following is Koen’s definition of heuristics: “Anything that provides a plausible aid or direction in the solution of a problem but is in the final analysis unjustified, incapable of justification, and potentially fallible with the following signatures:”

- A heuristic does not guarantee a solution
- It may contradict other heuristics
- It reduces the search time for solving a problem
Its acceptance depends on the immediate context instead of an absolute stand.

Regarding our understanding of heuristics, for example, the ability to try to solve unsolvable problems (such as complex problems) or to reduce the search time for a satisfactory solution are characteristics by which a heuristic may be recognized. In Koen’s words: “Some problems are so serious and the appropriate scientific technique to solve them are either non-existent or so time consuming that a heuristic solution is preferable to none at all.” His words echo those of Descartes (Cottingham 1986).

In a construction project, uncertainties (Bertelsen 2005, 2004, 2003; Bertelsen and Emmitt 2005) are due to temporary coalitions in a turbulent environment requiring semi-predictable or even unpredictable configurations of supply industries and technical skills. Groák (1992, 1994), and Polanyi (1967, 1974), call these “technological paradigms” organized around a “project” and not the “firm or production process” (Nightingale 2000) a major paradoxical distinction between construction and manufacturing. Paradoxically although the axis of a project is essential, the defining characteristic of the systemic nature of building construction is a “dynamic process.”

A clear distinction between construction and the traditional definition of an industry, like manufacturing, is essential for an understanding of the systemic nature of the “industry.” The capacity of the industry (Hillebrandt, 1975, quoted by Pearce 2006) is revealed in the use of different distinct resources and skill bases for different building types and different construction sectors (civil, building, industrial, manufacturing, housing, medical). These construction sectors are in fact different “industries,” according to Kodama (1992): “We are moving away from the idea of ‘one technology, one industry’ as the framework of analysis for building construction capacity for change.” Furthermore, not only are we moving away from an understanding of construction as encompassing only one industry, but of several industries (Kodama 1992), and altogether from the model of an “industry” as understood in manufacturing and defined by “industrial science” theories and practices.

Groák states “we should no longer treat construction activities as belonging to ‘an industry’ with definable boundaries, specific technical skills and using specific resources.” The focus is continually shifting more and more towards its end-products and services, recognizing increasing external linkages and potential innovations from beyond “construction” where the construction capacity resides according to Hillebrandt (1974, 1975, 1984), a position embraced by Pearce (2003, 2006) and followers.
6.3. Metaphysical basis for distinctions between product and processes

The reason for this metaphysical excursion into the distinction between product and process (artifact and becoming) is to create as firm a foundation as possible for a worldview of building construction that is based on state of the art heuristics.

Koskela and Kagioglou’s (2006) research states that since the pre-Socratic period, there have been two basic metaphysical worldviews. The thing-oriented view seems to lead to analytical decomposition, the requirement or assumption of certainty and a more static philosophical approach. On the other hand, the process-oriented view relates to a holistic orientation, acknowledgement of uncertainty and to historical and contextual approaches.

Koskela and Kagioglou (2006) argue that “production” is intrinsically a process-oriented endeavor. However, an analysis of current conceptualizations shows that it is the thing-oriented view of the world (product) that has dominated research and practice of production management (Nightingale 2000). What the authors mean by this is that research and production management practices have used the Cartesian method of problem decomposition (Descartes’ second rule, 1898, quoted in Cottingham, 1986). Thus, according to Koskela and Kagioglou (2006), the general direction of research (and production management) is achieved by going into even smaller parts of the whole and searching for explanations at the lowest possible reductionist level, as used by Newton and followers, also known as the scientific approach.

The two underlying assumptions behind the thing-oriented worldview as related to decomposition are: (i) similarity and (ii) independence of decomposed elements or parts. Koskela and Kagioglou (2006) state: “the similarity assumption takes it for granted that the parts are, by nature, similar to the whole and thus also mutually similar. The assumption of the independence of parts follows from the similarity assumptions. Namely, if our unit of analysis is an idea, problem or thing in itself, so will all decomposed parts also be ideas, problems or things in themselves.”

On the other hand, process metaphysics holds that “everything flows” and is in “change.” According to Rescher (2000), a contemporary understanding of process metaphysics, as quoted by Koskela and Kagioglou (2006), follows:

- Time and change are among the principal categories of metaphysical understanding;
- Processes are more fundamental than things (i.e. projects) for the purposes of ontological theory;
- Contingency, emergence, novelty and creativity are fundamental categories of (process) metaphysics.
Rescher (2000) defines process as a structured sequence of successive stages or phases, having three characteristics (thus establishing the criteria for processes):

- A process and a product are duals of each other.
- A process and a product have a relativistic space-time and time-space relation to each other found in relativity theory.
- There is a process phase and a product phase of the phase space of the entity.
- Processes and products vary along a spectrum from simple to complex.
- Both processes and products can have parts, but the parts of processes are staged in time.
- Processes take place in relation to a reference while products appear in the background of other processes.
- Thus perceptually, processes and products are based on flow and gestalt. Flows can be seen as temporal gestalts, where it takes time for the figure to appear on the background, while spatially simultaneous to the appearance of products on their ground.
- Unity and totality and wholeness of processes and products are not intrinsic but something which appears as we look at the mereology (whole part relations within the process and product).
- At the pattern level there are structures and flows as well as signs and values.
- At the form level there is the shape and behavior of an object as well as states and events (such as receiving messages).

Construction, to build, as a verb, an activity, is about “change.” To have a building is to have first the activity that created the building as understood by Aristotle. Imai’s (1986) Kaizen observes that there are two types of changes: abrupt change such as the difference between two sets of things (i.e. the natural and the artificial environments) and change as the process between the now and the after now.

Aristotle’s “Human beings become builders by building” suggests that becoming a builder happens only in the process of building itself. It does not happen outside that process. In other words, construction deals with embodiment. The theories of architects and engineers become embodied in construction, or for engineers it is technicians who actually handle the work that is performed under the supervision of the engineers. This split between construction people and architects, or technicians and engineers is an image of the mind/body split in our society, just as the split between industry and academia in general is another image of that dualistic split.

A plausible reason that construction has no theory may be because it is seen as an image of the body, not the mind. But embodiment is a problem which is becoming more and more prevalent in philosophy and has become more important recently. Thinking though embodiment follows pathways other than pure thought about ideas. Embodiment is messy. Embodiment is amorphous and ambiguous. The construction
process and site comprise a meta-system which brings to embodiment a system that has been designed by the architect, who has picked this system out of the landscape of possible designs which is again a meta-system. One can see that, in construction, systems and metasystems are intertwined on multiple levels.

Changes occur at a macro level (industry, economy, society) and micro level (the firm, project specific organization and the project itself). The essence of this activity is environmental change: where there was nothing, now there is a building, through the process of construction. Because the arena of change is the natural environment interacting with an artificial environment, it can be argued that building construction, as well as construction in general, is a process, but with a project’s outcome (product) as its essential secondary axis. As a process, it is always “now this, then that”; it is complex as we have noted, with a temporal and in-eliminable spatial-temporal dimension; furthermore, the building construction process has its own structure. In contrast, manufacturing is a product but with a process as its essential secondary axis (see Fig. 5). This is like the difference between the space-time and the time-space matrix. Manufacturing operates in space-time and construction in time-space (see Heidegger’s book on Time and Being). Minkowoski describes time-space over against the representation of space-time by Einstein. This represents two ways of looking at four dimensional reality emphasizing space on the one hand or time on the other hand.

Fig. 5 Systems abstraction
Mass product manufacturing is a tightly coupled system (with product in its main axis and process as the enabling characteristic), whereas building construction is a loosely coupled system (Dubois and Gadde, 2000), a process as its main axis and product, which highlights the difference in the two systems (Nightingale 2000). Mass product manufacturing, as a tightly coupled industrial system, exhibits the following characteristics:

- Delays are not allowed or possible
- Sequence of events are invariant (except in flexible manufacturing schemes)
- Alternative paths are tightly controlled or not available
- Little or no opportunity for substitution or repair (usually discarded, wasted)
- Slack is not desirable
- Redundancies are designed and deliberate

In contrast, building construction, as a loosely coupled system, exhibits the following characteristics (Dubois and Gadde 2002; Nam and Tatum 1988):

- Number of permutations and possible combinations are enormous (Weick 1994, 2000)
- Complex operations (Gidado 1996)
- Inefficient operations (Cox and Townsend 1998)
- Sub-optimization (Gann 1996)
- Some tightly coupled, some time sensitive specialized activities with sequentially interdependent activities with standard parts (Gidado 1996)
- Mostly, it is a loosely coupled system (Dubois and Gadde 2002)
- Overlapping activities; long lead time and slack built in
- Adaptive on-site changes (Vrijhoef and Koskela 2005a) and consequential changes (Crichton 1966)
- Generation of variations (Akintoye et al 2000)
- Self-determination; coordination with different firms, each adding a measure of slack
- Work is redone when non-conforming, rather than product discarded as in manufacturing

It is reasonable to infer that building construction as a process is bounded at the upper end of the taxonomy by systems (and even meta-systems) with complex process driven entities. However, at the same time, the boundaries at the lower end are assemblies that are product driven entities (see Fig. 6). Perhaps this duality of process and product underlies the thinking of the proponents that want to make building construction more like manufacturing--product driven.
Building construction’s capacity for change is therefore an intrinsic source as well as a recipient of variability, inefficiency, non-linearity, and comfort with chaos, creativity, novelty, uniqueness and even paradox and ambiguity, i.e. all the problems associated with embodiment. A high capacity for change implies freedom at many levels of the taxonomy. In other words, the meta-systems nesting allow a high degree of inventiveness, promotes creativity, and celebrates diversity.

The capacity for change is furthermore exacerbated at the product end and the client himself is a complex system and source of variability (Cherns and Bryant 1984; Pries et al. 2004). This “product” axis of the paradox also exhibits the characteristics of: uniqueness, expression, one-of-a-kind, on a particular site with particular characteristics, actors selected and acting autonomously (Koskela 2000).

It is then prudent to say that from both the supply and the demand side, from the process and the product, and as a matter of fact from the milieu where building construction takes place (the universe of a meta-industry), the fundamental characteristics of building construction are those of a complex system, process driven with a normative capacity for change.

7. Towards an understanding of the complex nature of the industry

According to Chu et al (2003), there is no generally accepted definition of complexity, no universal and unified Theory of Complexity (TOC) and, according to critics; complex systems are too diverse to share any profound “common causes for common characteristics.” Furthermore Chu has also observed that at a higher level
in the field of the philosophy of science, there is no unique, simple criterion or litmus test to decide if a theory is scientific or not. Thus rather than looking for a universal criterion for being scientific, it is often better to ground criteria in the aim of the theory or a heuristic (Koen 2003). According to Chu et al. 2003, three aims are central:

**Predictive component:** prediction of the future behavior of a system, given a set of observational data about it; an active quantitative prediction and experimental manipulation of phenomena.

**Exploratory component:** theoretical understanding and/or explanatory description of a system / framework for a number of phenomena.

**Control component:** provision of guidelines and control mechanisms for the intervention and manipulation of a system; ability to manipulate the exploitation of scientific theory.

Ideally then, a scientific theory would explain, predict, and facilitate control at the same time. However, all scientific theories do not follow the list of mentioned components but may emphasize one of the components while the others are treated as negligible factors.

Chu et al. (2003), in addition to the above criteria, makes the following pertinent observations (emphasis added):

“A central and related issue is the language in which a TOC is to be formulated. Science is largely dominated by a Platonist ideal (Koyre 1968). The essence of this ideal was established in mechanics by Galileo and its most important success is... theoretical physics. Often a TOC is (more or less tacitly) assumed to be a mathematical theory (Gödel 1931). Holland, for example points out that the mathematical form has the additional advantage of high precision and generalization. One may add that prospects of prediction and control might look better if a mathematical form is possible. Indeed quantum theory is wholly formalized and quantitative. In contrast, the theory of biological evolution by means of natural selection, for example, involves mathematics only for the formulation of detail, whereas the main insight is formulated in natural language. A TOC might be of this latter kind.”

Borrowing from Koen (2003), TOC might be realistically considered “heuristic.” An additional observation by Chu et al. (2003), and reiterated by others, is:

“Another element that is tightly woven into a Platonistic/Galilean paradigm is the idea that natural systems can be separated into relatively simple essence
plus irrelevant perturbation or ‘friction.’ The latter acts like a curtain to hide the basic principles of nature’s workings.”

Another important property of TOC is universality: A TOC should be applicable to most, if not all, of a wide range of different complex systems. Chu et al. (2003) states that:

“… in a Platonist/Galilean science tradition the idea of ‘universal theories’ is often equated with ‘unified theories.’ Although unification is of a highly aesthetic value, it should not be regarded as a litmus test for a universal TOC.”

We would expect a TOC to be useful in: controlling natural systems, or to be predictive, or to be explanatory. It should make some claim of universality. However one would expect a possible trade-off between universality and mathematical quantitiveness and it may or may not exhibit “unification” characteristics.

### 7.1. Systems thinking and the construction industry

Richmond (1993) uses the term “Systems Thinking” as a replacement for the term “systems dynamics.” Richmond suggests seven critical “systems thinking” skills and the need to operate on all seven thinking tracks simultaneously.

The term “systems thinking” is somewhat of a paradox (Davidz et al. 2006; Zemke 2001), since this phrase combines words that imply individual and multi-actor concepts into one research construct. This creates difficulty in selecting the unit and level of analysis: the unit of analysis is the entity being described or analyzed during a research study (in construction the unit and level of analysis can be: macro - industry; and micro - project and firm). Four standard levels of analysis in social sciences are individuals (inventors, entrepreneurs); groups (social and cultural groups); organizations (building construction); and environments (natural and artificial environments). Individual characteristics, group dynamics, organizational culture, and surrounding environments all affect the system of interest in multi-level interactions, thus producing a “wicked” problem atmosphere.

Richmond (1993) suggested seven critical systems thinking skills: dynamic thinking, closed-loop thinking, generic thinking, structural thinking, operational thinking, continuum thinking and scientific thinking. He suggests that good “systems thinking” tracks simultaneously all seven skills. Once the unit and level of analysis are established, we can make some observations on the nature of the building industry.
7.2. Observations on the nature of the building industry (what is the unrecognized or unrecognizable complexity in systems).

Complexity in building construction (Bertelsen 2005) has been studied from different perspectives; for example, as part of managing complexity in project production (Bertelsen and Koskela, 2002, 2005), and seeing the client as a complex system (Bertelsen and Emmitt, 2005; Emmitt 2003; Bertelsen 2003; Lucas 2000, 2004, 2005; Pries 1995, et al. 2004).

Managing complexity in project production is an attempt (Shewhart 1931; Shewhart and Deming 1939) to minimize variability to get the productive activity under control. The aim of this approach is to avoid complexity and uncertainty, which could disturb tight controls. Recently this approach has been championed in Lean Construction (Alarcon 1997; Ballard, et al. 2002), Last Planner (both are service trademark of the Lean Construction Institute, USA) and Just in Time theories and practices. However, as noted by Bertelsen (2005), there are production situations with inherent complexity and unpredictability that escape efforts at reducing complexity, codifying procedures, learning to improvise, and buffering.

These approaches result in a paradoxical inverse linkage with effectiveness and efficiency. Efforts at reducing complexity also rub against the nature of a meta-system characterized as a fertile breeding ground for inventions and innovations, where technologies created for other sectors are adopted and assimilated successfully. In other words, control of waste is the opposite of variability and variability is the breeding ground of possibilities. Hence building construction has recognizable and unrecognized complexity (as in a “meta-system”), and acts more like a complex, dynamic, living organism that is self-organizing (Kaufman, 1993) and adaptive as in a learning organization rich with waste and with innovation possibilities. There are complex systems and complex meta-systems. These two are different, a subject that will be further elaborated in future work.

Client complexity (Pries et al. 2004), and its attendant consequences, showcase chaos theories where the lack of initial definition or moving targets along the phases creates ripe conditions for divergence. We shall investigate in greater depth the understanding of complexity, in relation to building construction, as published in refereed journals.

System and meta-system are schemas; complexity, and adaptivity are extensions of these schemas. With this in mind, complexity, according to Baccarini (1996), can be operationalized in terms of differentiation and interdependency. Some authors (Waldrop, 1992; Lorenz, 1972, 1993; and Kauffman, 1993, 1995) state: “complexity lacks a generally accepted comprehensive definition.” Bertelsen (2005) asserts that almost any system can be seen as complex. In this light, complex systems are not a special class of systems, but a way of looking at any system as opposite to the
ordered, reductionist worldview where systems are decomposed into parts that are analyzed with the expectation that the parts reveal the system and vice versa. In this context, complexity studies mean studying the system as a whole without simplifications and observing the interactions between elements and systems as much as the elements and systems themselves.

This approach is characterized by non-linearity and richness in feedback loops where a formal analytic approach is no longer possible or desirable. A new way of looking at complex systems is provided by Lucas (2000), who identifies a comprehensive list of 18 characteristics found in complex systems. This list is considered by other researchers (Bertelsen 2005) as fairly exhaustive. A closer examination of these characteristics as related to building construction, allows a grouping into three categories: autonomous agents; undefined values and non-linearity. Furthermore, Bertelsen (2005) relates these types to one of the three aspects of construction advanced by Koskela (2000): transformation, value and flow.

However, what is considered a holistic, systems view is also considered a reductionist view when the boundaries of the point of perspective are re-drawn. Two examples are proposed, one from the aircraft industry, and the other from the construction industry. Davidz (2006) supplies the following example that has been adapted: Consider an aircraft engine: a “system” could be a part (a set of compressor blades called the compressor stage), a component (a compressor), a subsystem (an aircraft engine), a production system (an aircraft), a group of design engineers (Advanced Compressor Design), a business (GE Aircraft Engineers), a larger business (GE), a sector (the aerospace sector), a national general economy (USA), or the global system (air transportation). The definition of a system and the point of view that makes it holistic is therefore driven by the end-state or application of interest. All these same things can be seen as meta-systems as well. This shows that schemas are projected on things as templates of understanding by which we see different bases of order in the things which are not necessarily part of the things themselves, but are adumbrations to which the things themselves fit more or less well.
Building construction, in contrast, has a component (motor), a production system (mechanical system), a business (air conditioning), a larger business (a building) with multiple and disparate systems (elevator, plumbing, electrical, structural) that make it a meta-system, is part of the building sector, part of construction, a national general economy and the global system of satisfying human needs for security and shelter from the natural environment.

In the general schema proposed earlier, building construction fits as follows (see Fig. 7 Proposed general taxonomy).
Building construction (as part of construction in general, not shown for clarity) is listed as a subset of the industrial sector of the general economy. The industrial sector also forms the background where the systems components, sub-systems, suppliers, vendors and manufacturers reside. Hence, building construction, a dynamic process that we have seen, is bracketed by the notion or reality implied in the word “industry.”

Bertelsen (2005) groups 14 of the complex system characteristics (taken from Lucas 2004; Nam and Tatum 1988) into the three previously noted categories. We have taken this list, expanded to the full 18 elements (see Table 1) from Lucas (2000, 2004, 2005) and added information from Koskela (2000) and Shingo (1988).

<table>
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The following expands Lucas’ definition of the elements found in a complex system:

1.1 **Autonomous Agents**: Stakeholders are varied, not identical, with differing perspectives and interests, which change over time.

**Non-Standard**: The system is heterogeneous and allows varying associations over time.

**Co-Evolution (self-organization)**: The parts may evolve in conjunction with each other in order to fit into a wider system.

**Self-Modification**: Parts can change their associations or connectivity freely.

**Downward Causation**: A system is made up of its parts, and the parts are affected by the emergent properties of the whole system.

**Self-Reproduction**: The system can replicate itself.
Mutability: Random interval changes may occur in the system.
Fuzzy Functions: The overall function (purpose) of the system is co-evolved.

2.1 Undefined Values: The meaning of the system’s interface with its environment is not specified at the outset.
2.2 Fitness: The distribution of choices can be modeled using the concept of fitness landscapes, with local optima and global optimum that are relative and dynamic
2.3 Non-Uniform: The system is different and evolves in time in response to internal and external demands.

3.1 Non-Linearity (non-equilibrium): The system operates far from equilibrium since it takes energy from its environment
3.2 Emergence: System properties are higher-level meta-systemic functions of the system (Peitgen, 1986); emergent phenomena travel from specifics to generalities and vice versa as well as from systems to ambiance and vice versa.
3.3 Attractors: The system has multiple dynamic attractors; it can be stable for a while, but not permanently.
3.4 Phase Changes: The feedback may lead to sudden jumps to another relatively stable phase.
3.5 Unpredictability: The system is chaotically sensitive to its initial conditions
3.6 Instability: Over the long-term step changes or catastrophes occur.
3.7 Learning Organization: The organization evolves by learning from experience and errors.

The state of the art research in peer reviewed publications derives these complex characteristics from the construction industry. Lucas’ 18 characteristics as grouped by Bertelsen (2005) (and adapted in this analysis) with the headings provided by Koskela (2000) and Shingo (1988) are then analyzed using as a background Richmond’s seven skills for complex thinking (see Table 2). The matrix illustrates the intricacy of a full analysis of complex systems from a “thinking” perspective. Although a written matrix depicts the theoretical fullness of an analysis, in practice these procedures are customarily performed flexibly, to some degree.

Complexity and flexibility are, according to Moses, the coin in the realm of systems that allows expending complexity dollars to achieve useful gains such as increased functionality, efficiency and/or flexibility. For example, we now consider the three main groups identified by Bertelsen (2005)–autonomous agents, undefined values and non-linearity–as they apply to building construction, using a systems thinking approach.
The purpose of Table 2 is to identify the matrix of complexity that could be used in future research. For example, each line item and thinking column needs the identification of its characteristics and performance metrics to create a more granular picture of the systemic nature of the industry. Let us briefly explore Bertelsen’s (2005) autonomous agents, undefined values and non-linearity, and analyze them with the seven layered thinking process as an example of what can be done with the others.
Autonomous Agents

Complex systems, such as building construction, are composed of independent or autonomous agents that are not identical. By design, no permanent executive or directing node exists in the system, with a control structure or leadership that emerges through self-organization. This self-organization (Kaufman, 1993) evolves and acts as an emergent control structure for the product and the process (Abdelhamid, 2004). These characteristics highlight non-linearity, learning organization, self-organization, and downward process causation, with high variability and therefore unpredictability.

The autonomous agent element is found between levels of the schema (sub-contractors, system components, construction services, design services), as well as within each level (i.e. construction services). For example, in construction services, one autonomous group (the formal control structure) plans the project with a management-as-planning-and-dispatch modality and another autonomous group (the informal control structure) builds the project where self-modification, a learning organization, dealing with unpredictability and variability establish non-uniform variation from the formal control structure (Koskela and Howell 2002).

A design is uniquely created for the one-of-a-kind, on-site project by a team assembled for the task (varying from project to project) which necessitates a co-evolution of (a) the process, (b) the organization and (c) the project that is unique to the project. This co-evolution of elements aims to fit the created “fitness landscape” and achieve the “local maxima” (terms explained in the next section) while keeping in mind the global maximum that has been (sometimes) established (to varying degrees), but that can change during the project’s gestation. New materials, methods, design solution, processes and others require self-modification and a learning organization.

Undefined Values

The boundary of a system in the building construction arena is not initially specified and evolves in dynamic communication to fit a landscape that, itself, is emerging. The concept of fitness landscape in this sense reflects the finding of the “local optima” high ground, for each part of the project, the process and the organization (be it design or construction or both). This is advanced through mutations in regard to an established (directly, indirectly or implied) relative global optimum in a balancing act between quality, cost and time as well as efficiency and effectiveness. However, this process does not occur at one level but at multi-levels in the schema, creating a matrix environment of negotiations with no global optimum possible, a major characteristic of a complex system and thus a wicked problem.
The undefined value alludes to the non-standard and non-uniform one-of-a-kind product and process that happens in space and time. The freedom of association or movement permits the clumping and de-clumping over time as the self-organization structures itself, the process as well as the product. This dynamic freedom aims towards the goal of creating value, albeit undefined, as we shall see. This value exists even if a project ends up in court, as it generates value for the litigation system at the expense of other stakeholders.

Every project establishes (explicitly or implicitly and to varying degrees) its own economic fitness landscape, quality fitness landscape, performance fitness landscape, and cost fitness landscape during the initial design stage. Fitness landscape in this sense can be considered as a term that encompasses, among others, the concepts underlying building performance indicators.

“It is the nature of the project that it exists in its own fitness landscape,” states Bertelsen (2005). This fitness landscape includes, from the organizational side, the design and production (construction) components in differing possible combinations called Project Delivery Systems. However, the fitness landscape is emergent with the building construction sector, the industrial sector, the general economy and social system to name a few upstream, as well as downstream with sub-contractors and vendors. Each possible combination eventually affects the project’s local optima (component of phase) as well as the project’s global optimum. Therefore local optima, due to the aforementioned unpredictability, attractors, phase changes and variability (instability), creates local optima and global optimum much lower than expectations.

Unpredictable local optima has been the major complaint (Fisher 1993, Gann 1996, Johnson 1995, Winch 2003) when comparing building construction with other sectors such as manufacturing where aircraft (Barber et al. 1998; Voodijk and Vrijhoef 2003), ships and large complex systems reside but with differing parameters and control structures. The drive behind the move towards a manufacturing based construction industry is a desire for increased efficiencies, i.e. reducing initial cost or labor, as in other industries (Latham 1994, 1988; Egan 1998, 2002). In their opinion, the construction industry is fragmented, a flaw to be remedied (Gann, 1996; Pyke 2002; Woudhuysen and Abley 2004).

However, Dickson (2003) views industry outputs and outcomes as important, valuing, in addition to costing, a diverse, open, and flexible industry as something to be celebrated. The key in these contrasting positions is that manufacturing, as it is presently configured, is for mass production and this introduces a rigidity and inflexibility that runs contrary to the design and construction industry in its current configuration.
Bertelsen (2005) observes, and we concur, that there “does not exist an absolute optimum” for a project, thus the “best solution” is dependent on the system’s real-world status. Others may counter that, although relative in time, with the state of the art, a performance based building design coupled with a total building commissioning plan (NIBS 1999), can establish a “relative best solution” or “relative optimum” that can serve as a project goal (Altwies 2001). However, it is precisely problems without absolute optimal solutions that are wicked problems since the pre-conditions change as the solution evolves.

The project represents an emerging physical structure, and emerging process, through an emerging organization in time and space with increasing order and purpose and the intent of generating a specific value. This value, although constructed in the narrow sense for the client, ends up being a value for all levels of the general schema and thus the longevity and open structure of the industry, where variability is a key complexity characteristic.

**Non-Linearity**

Complex systems are non-linear: the outputs are not proportional to the inputs; the whole is different from the sum of its parts. A roof is just a roof; a house without a roof has much less value, if any.

The project itself acts as a dynamic attractor for an emerging organization of otherwise disparate stakeholders, autonomous agents with alliance to their parent organization. However, the temporary project organization for space and time self-organizes in formal and informal structures as a service, production and process system. The project dynamic contains multiple and sometimes conflicting attractions creating a matrix of possible and different behaviors within the project duration and between projects by the “varying team” factor. Within project “partnering” is an attempt to bring in line the sometimes-conflicting attractions (see Black et al. 2000 for success factors and benefits).

The initial configuration of the team is in constant flux, thus, a multitude of actors create the system history that, coupled with phase changes and milestones where transitions occur, not only places the project at the “edge of chaos” but is also a difficult history to capture fully for lessons learned exercises that would benefit a learning organization. These transitions are critical points in connectivity requiring the system (project, process and organization) to self-modify, self-organize and co-evolve to manage the fitness landscape, local optima and global optimum. The project organization’s limited time existence does not allow it to emerge to a higher plateau, even if it is an intermediary step from the next full level of meta-organization, virtual organization (integrated organization found in heavy industry, such as Petro-chemical).
In heavy industry, such as in a refinery, the high risk level and complexity require a smaller team that is relatively constant due to long project duration and teams moving from one project to the next seamlessly. One-of-a-kind solutions are discouraged, and lessons learned are fully captured (or catastrophes induce heavy insurance premiums that become a motivator to capture lessons learned and apply them through standards, regulatory framework and codes).

In buildings, understood as an assembly of systems (a system of systems), the wicked nature of the design as well as the construction processes and the client itself as a complex system (Bertelsen and Emmitt 2005; Emmitt 2003; Pries et al. 2004) makes it possible and most probable that small differences between stakeholders will lead to vastly different solutions, different processes and different project organizations. In other words, chaotic sensitivity to initial conditions makes a project rich in unforeseen events, deviation from plans and variability, thus affirming the concept of contextuality of a complex system.

The most critical decisions by the stakeholders are affected by the disposition or attitude towards what eventually becomes the project’s driving principle: cost, value or quality, which changes throughout the project phases and duration beyond the initial construction, its life cycle. The expressed, implied or inferred attitude of the stakeholders, individually and collectively, introduces sensitivity to chaos that is magnified through the project. The non-linearity of the project carries through the non-linearity of the building construction sub-sector, the non-linearity of the industry and the general economy. These additional levels of non-linearity upstream and downstream create a complex dynamic mechanism that is almost impossible to study in holistic or particular detail.

Lastly, building construction is nested in a social system with a varying team where communications and cooperation are emergent phenomena in each project. Cooperation is based on the project attractor for common behavior, sometimes based on experience and performance, but oftentimes based on low bid. Common behavior stabilizes the project’s cooperation (Bertelsen 2005) “in either a good or bad way” creating the “project culture.” This culture, however, reflects all the characteristics and attributes of the larger social culture that includes cooperation, fighting or fleeing behavior along with a myriad of other social types of behavior. Thus culture adds another dimension of unpredictability, with a number of entrants and departures disturbing the “project culture” stability in completely unforeseen ways.

This analysis of complexity in building construction does not pretend to be exhaustive. However, it illustrates how the project, process, emergent organization, culture, and the other mentioned characteristics of complexity, such as autonomous agents, undefined value and non-linearity, are intertwined. We postulate that the dichotomy of project/process in building construction is so blurred that it may be
theorized that a building is a project whose emergent and intrinsic quality is that of a process where the project, along with organization and all the supporting networks of services and products, forms the fundamental elements of the process.

In Palmer’s (2003, 2004) terminology, it is a meta-system formed by a paradox with two axes, project and process, and everything that comes within the boundary of that paradox will inherit the intrinsic paradoxical qualities. The project defines existence, while the process defines movement, if a differentiation needs to be made, although in reality they are one because they are mutually co-dependent, another characteristic of the paradox in meta-thinking.

8. Conclusions

We have analyzed past and current studies as a point of departure for an inquiry into the nature of systems that could help identify the necessary and sufficient characteristics that allows us to glimpse the systemic nature of the construction industry.

We focused on state of the art knowledge about “complexity” because this is, according to Popper, the (3rd world intelligible) construct that allows an understanding of the boundaries of the systemic nature of building construction (a 1st world reality) and the characteristics that we need to anticipate in our argument.

Construction’s reigning paradigm of being an “industry” does not quite capture the complexities embedded in the artifact or in the process of creating the artifact (infrastructure and/or a building) or the environment that allows such artifacts. The dynamics of construction go beyond systems dynamics due to the nature of its complexities. The application of current efforts to improve efficiency and effectiveness continue to generate significant differences between expectations and results. These differences point to anomalies between the current paradigm and its reality.

What is critical at this point in history is the relationship of the artificial environment with the natural environment. Specifically, the continually increasing creation of artificial environments using a framework that is lethargic in changes. Furthermore, continuing to create artificial environments as we have done in the past is not acceptable and gradual and step changes are inadequate to bring the magnitudes required for taming an unsustainable exponential growth. Efforts at radical change need to be supported with radical thinking. Paradigm shift is at the top of the philosophical pyramid of changes.
It is expected that this report will generate significant debate in the industry as we realize that we are in a pre-paradigmatic or paradigm shift phase whether we like it or acknowledge it or not.

If the concept or proto-theory that views construction as a meta-industry has merit, we conceptually discard “industry” as the locus for finding solutions and open up the possibility of looking elsewhere. This is a paradigm shift of the first order. Perhaps the best contribution of this effort is to pose the Socratic “why” questions, in the hopes of achieving a clearer thinking process. What are the implications of construction as a meta-industry? How does the artificial meta-system relate to the natural meta-system? These questions are relegated to further studies.

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