The Systemic Nature of the Construction Industry

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ABSTRACT

A worldview of the construction industry with its complexity provides a more realistic platform from where we can identify the elements that historically have influence industrial change and avoid the attraction and bias of reductionist models. This paper presents a better understanding of the complex nature of the building industry to answer the question: How can we postulate a type of system to be the right vehicle to study a phenomenon that cannot be extrapolated from past behaviour?

Keywords: Worldview, Construction Complexity, Systemic Nature, Manufacturing Industry

1.1 INTRODUCTION

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. Once these two items are in place we then proceed with pre-paradigmatic, analog thinking to construct the rules for a bridge between construction and its worldview.

If building construction has the characteristics of other mass production industries, then the models of these other industries would be satisfactory to manage construction complexity. However if building construction does not have the characteristics of other mass production industries, then a worldview different from that of manufacturing and industry is needed to understand complexity.

Furthermore, if building construction is not akin to manufacturing, and there are no models, we need to go one layer of knowledge higher and discern a worldview (paradigm) that allows us to realistically look at the industry (Ranta 1993). In this case, we may even have to reach back into a previous layer of knowledge, the archives of philosophy and the tools of
metaphysics and epistemology, to clarify the foundational concepts that inform a pre-paradigm. Therefore a clear distinction of the mechanisms and forces of manufacturing vs. building construction is critical.

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 is composed of 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 project and process. Construction in general does not behave as an ‘industry’ but more like a ‘conglomerate of industries’, an ‘industry of industries’, a ‘meta-industry’ 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.

2.1 TOWARD AN UNDERSTANDING OF THE SYSTEMIC NATURE OF THE INDUSTRY

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

“at 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 heuristics 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 in this paper, for example, the ability to try to solve unsolvable problems (such as complex problems) or to reduce the search time for a satisfactory solution is a characteristic 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 no solution at all.” His words echo Descartes 1637/1989 (Cottingham 1986): “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 last the reasons for selecting it are excellent.”

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. Groåk (1992, 1994) and Polanyi (1967, 1974) call these ‘technological worldviews’ organized around a ‘project’ and not the ‘firm or productions process’ (Nightingale 2000) a major paradoxical distinction between construction and manufacturing. Paradoxically, as we shall see in more detail later on, although the axis of a project is essential, the defining characteristic of the systemic nature of building construction, is a ‘dynamic process.’ (This dynamic process is similar to Hawkin’s (1996) paradox: a moving train where a passenger and a platform viewer have different perspectives of the same event).

2.1.1 A distinction between construction and manufacturing industries

A clear distinction between construction and the traditional definition of an industry, like manufacturing, is essential for an understanding of the systemic nature of ‘industry.’ The capacity of the industry (Hillebrandt, 1975, quoted by Pearce 2006) is revealed in the use of distinct resources and skill bases for different building types and different construction sectors (civil, building, industrial, manufacturing, housing, medical, etc.) 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 one industry, but rather several industries (Kodama 1992), we are also moving away, altogether,
from the model of an ‘industry’ as understood in manufacturing and defined
by ‘industrial science’ theories and practices.
Groåk 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 should be more toward 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.

We concur with Kodama (1992) and Groåk (1994) and appreciate the
direction on building construction’s capacity for change. Our position,
however, is that the concept of a meta-industry contains a world of
paradoxical order and disorder that has not been explored as a better
descriptor of the essence and processes encompassed in the notion known
as ‘building construction.’

2.1.2 Metaphysical basis for distinctions between product and
processes

The reason for this metaphysical excursion is to create as firm a foundation
as possible for a worldview of building construction that is based on state of
the art heuristics in our evolutionary process.

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, 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 (Palmer 2001b,
2004 and others).

Koskela and Kagioglou’s (2006) research states that since the pre-
Socratic period, there have been two basic metaphysical worldviews. One
holds that there are substances of things (being), that is, atemporal entities
in the world. The other insists that there are processes (becoming), that is,
intrinsically temporal phenomena. These metaphysical assumptions
(things, being, entities – products; becoming, atemporal – processes)
strongly influence how the subject of the inquiry or action is conceptualized.

The thing-oriented view leads to analytical decomposition, the
requirement or assumption of certainty and a historical-philosophical
approach. On the other hand, the process-oriented view is related to a
holistic orientation, acknowledgement of uncertainty and to a historical and
contextual approach.

Koskela and Kagioglou (2006) argue that ‘production’ is intrinsically a
process-oriented endeavor. However, an analysis of current
conceptualizations and methods 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, 1637/1898, quoted in Cottingham, 1986). Thus, according to Koskela and Kagioglou (2006), the general direction of research (and we may add production management) is achieved by going into even smaller parts of the whole and searching for explanations at the lowest possible level, a method 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 ‘change’. According to Rescher (2000), a contemporary understanding of process metaphysics, as quoted by Koskela and Kagioglou (2006) is:

- 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), as shown below:

- A process is a complex, a unity of distinct stages or phases (a process is always a matter of now this, then that).
- This complex has a certain temporal coherence and unity, and that the processes accordingly have an ineliminable temporal dimension.
- A process has a structure, a formal generic format in virtue of which every concrete process is equipped with a shape or format.

### 2.1.3 Philosophical understanding of capacity for change

From a purely 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. In Koen’s (2003) all-is heuristic worldview, ‘capacity for change’ and ‘change’ are both part of a universal heuristic, period. No further derivation or definition is needed.

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, “Nicomachean Ethics,” 2.1.1103a35: “Human beings become builders by building.” 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 environment, and change as the process between the now and the after now.

![Figure 473.1 Systems Abstraction](image)

Changes occur at a macro level (industry, the economy, society), as well as a 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 the change is the natural environment with an artificial environment, it can be argued that building construction as well as construction in general, is a process, but with a project (read 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 ineliminable spatial-temporal dimension; furthermore the building construction process has a structure. In contrast, manufacturing is a product but with a process as its
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), with process as its main axis and product as the enabling characteristic, which highlights the difference between 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
- Alternative paths are tightly controlled or not available
- There is little or no opportunity for substitution or repair (usually discarded, wasted)
- Slack is not desirable
- Redundancies are designed and deliberate

![Figure 473.2 Building Construction abstractions](image-url)
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)
- 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 meta-systems with complex process driven entities (see Figure 473.1). However, at the same time, the boundaries at the lower end are assemblies that are product driven entities (see Figure 473.2). Perhaps this duality of process and product underlies the thinking of 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, and non-linearity. It is comfortable with chaos, creativity, novelty, uniqueness and even paradoxes and ambiguities. A high capacity for change implies freedom at many levels of the taxonomy. In other words, the meta-systems nesting allows a high degree of inventiveness, promotes creativity, and celebrates diversity.

The capacity for change is furthermore exacerbated from the product end and the client himself as 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, being one-of-a-kind, on a particular site with particular characteristics, with 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 as well as from the product, and as a matter of fact from the milieu where building construction takes place itself, the universe of a meta-industry, that the fundamental characteristics of building construction
are those of a complex system, a process driven with a normative capacity for change.

2.1.4 Toward 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 also observes 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 universal criteria for being scientific, it is often better to ground criteria in the aim of the theory or in a heuristic (Koen 2003). According to Chu et al. 2003, three aims are central:

- **Predictive component**: prediction of a system's future behavior, given a set of observational data about it; an active quantitative prediction and experimental manipulation of phenomena.
- **Explanatory 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 all mentioned components but may emphasize one of those 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 as ‘heuristic.’ The additional observation by Chu et al. (2003), reiterated by others noted in this paper 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 a wide range of different complex systems, if not all. Chu et al. (2003) state 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 quantitativeness and it may or may not exhibit ‘unification’ characteristics.

2.2 SYSTEMS THINKING AND THE BUILDING INDUSTRY

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 difficulties in selecting the unit and level of analysis. A 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 (the natural and artificial environments). Individual characteristics, group dynamics, organizational culture, and surrounding environments all affect the system of interest in multi-level interactions, thus creating a ‘wicked’ problem atmosphere. In this paper we have identified ‘elements of influence’ as one of the units of analysis and thus it can be an individual person, a relationship, a social grouping, an organization, a sector, etc. These ‘elements of influence’ are each a ‘generator of complexity’ in a radically open system with the innate characteristic of contextuality.

Richmond (1993) suggested seven critical systems thinking skills which are as follows: dynamic thinking, closed-loop thinking, generic thinking, structural thinking, operational thinking, continuum thinking and scientific thinking. As mentioned, Richmond suggests that good “systems thinking” tracks simultaneously all seven skills. However, before we attempt to apply these seven “systems thinking” skills we must make some observations on the nature of the building industry.

2.2.2 Observations on the nature of the building industry (what are 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 bring the productive activity under control. The aim of this approach is to avoid complexity and uncertainty, which could disturb tight controls. Recently this approach is championed in Lean Construction (Alarcon 1997; Ballard, et al. 2002), Last Planner1 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 buffer.

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1 Lean Construction and Last Planner are service trademarks of the Lean Construction Institute, USA (Ballard 2000)
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 unrecognizable 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.

Client complexity (Pries et al. 2004) and its significant consequences, showcase chaos theories where lack of initial definition or moving targets along the phases create ripe conditions for divergence, as will be noted later on. First, we shall investigate in greater depth the understanding of complexity, in specific relation to building construction, as published in refereed journals.

Complexity, according to Baccarini (1996), can be operationalized in terms of differentiation and interdependency. Some authors such as Waldrop (1992), Lorenz (1972, 1993), and Kauffman (1993, 1995) who state: “complexity lacks a generally accepted comprehensive definition”. Bertelsen (2005) asserts that almost any system can be seen as being complex. In this light, complex systems are not a special class of systems, but a way of looking upon 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 schema for 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 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, from a construction process perspective.

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, the aircraft industry and the construction industry. Davidz (2006) supplies the following example: Consider an aircraft engine: a “system” could be a part (a set of compressor blades called the compressor stage), a component (a
compressor), a sub-system (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 (US), 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.

Building construction, in contrast, has a motor as component, a production system (mechanical system), a business (air conditioning), a larger business (a building) with multiple and disparate systems (elevator, plumbing, electrical, structural etc.) that make it a meta-system, is part of the building sector, of construction, of a national general economy and of the global system of satisfying human needs for security and shelter from the natural environment.

In the general schema proposed in earlier chapters, building construction fits as follows (see Figure 473.3 Proposed general taxonomy).
Building construction (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 systems characteristics (taken from Lucas 2004; Nam and Tatum 1988) into three aforementioned categories. We have taken this list, expanded to the full 18 elements from Lucas (2000, 2004, 2005) and added information from Koskela (2000) and Shingo (1988).
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.

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

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

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

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

1.6 **Self-Reproduction**: The system can replicate itself.

1.7 **Mutability**: Random interval changes may occur in the system.

1.8 **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 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 ambience (milieu) 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.

Following is the state of the art interpretation by peer reviewed publications projecting these complex characteristics onto the construction industry, a work that is in progress. Lucas’s 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 473.1). 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 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 473.1 is to identify the matrix of complexity at this point in time, that could be used in future research to filter the elements that influence the industry and thus become the vectors affecting the construction industry. From this matrix we adapt 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.
Table 473.2 is more complex. If to this table we add a third dimension (say perpendicular to the sheet), the ‘element of influence’, we then have a three-dimensional matrix for analyzing the ‘elements of influence.’ This three dimensional vectorial calculus.

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<td><strong>3.1 Non-Linearity</strong></td>
<td>A3.1</td>
<td>B3.1</td>
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<td>E3.1</td>
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<td>G3.1</td>
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<td><strong>3.2 Emergence</strong></td>
<td>A3.2</td>
<td>B3.2</td>
<td>C3.2</td>
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<td>E3.2</td>
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<td><strong>3.3 Attractors</strong></td>
<td>A3.3</td>
<td>B3.3</td>
<td>C3.3</td>
<td>D3.3</td>
<td>E3.3</td>
<td>F3.3</td>
<td>G3.3</td>
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<td><strong>3.4 Phase Changes</strong></td>
<td>A3.4</td>
<td>B3.4</td>
<td>C3.4</td>
<td>D3.4</td>
<td>E3.4</td>
<td>F3.4</td>
<td>G3.4</td>
</tr>
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<td><strong>3.5 Unpredictability</strong></td>
<td>A3.5</td>
<td>B3.5</td>
<td>C3.5</td>
<td>D3.5</td>
<td>E3.5</td>
<td>F3.5</td>
<td>G3.5</td>
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<tr>
<td><strong>3.6 Instability (variability)</strong></td>
<td>A3.6</td>
<td>B3.6</td>
<td>C3.6</td>
<td>D3.6</td>
<td>E3.6</td>
<td>F3.6</td>
<td>G3.6</td>
</tr>
<tr>
<td><strong>3.7 Learning Organization</strong></td>
<td>A3.7</td>
<td>B3.7</td>
<td>C3.7</td>
<td>D3.7</td>
<td>E3.7</td>
<td>F3.7</td>
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2.2.2.1 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’s element is found between levels of the schema (such as sub-contractors, systems components, construction services, and 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 unique for the one-of-a-kind, on-site project created 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 gestation. New materials, methods, design solutions, processes and others require self-modification and a learning organization.

2.2.2.2 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 with a varying team that happens in space and time. The freedom of association or movement permits clumping and de-clumping over time as the self-organization structures itself, the process as well as the product. This dynamic freedom aims toward creating value, albeit undefined, as we shall see. This value, exists even in a project that 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. “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 subcontractors and vendors. Each possible combination eventually affects the project’s local optima in a component of a phase, as well as the project’s global optimum. Therefore the local optima due to the aforementioned unpredictability, attractors, phase changes and variability (instability) create a 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 toward a manufacturing based construction industry is a desire for increased efficiencies, i.e. reducing initial cost or labor, like 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, is important and a diverse, open, and flexible industry should 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

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2 “Fitness landscape” in this sense can be considered as a term that encompasses, among others, the concepts underlying ‘building performance indicators.’
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, for the longevity and open structure of the industry where variability is a key complexity characteristic.

2.2.2.3 Non-linearity

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

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 a specific 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 the 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, or integrated organization that is found in heavy industry, such as petro-chemical and others.
In heavy industry, such as a refinery, the high risk level and complexity require a smaller team that is relatively constant due to long project durations and teams moving from one project to the next seamlessly. Where one-of-a-kind solutions are discouraged, lessons learned are fully captured (catastrophes incur 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 toward what eventually becomes the project’s driving principle—cost, value or quality—which changes throughout the project’s phases and duration beyond the initial construction, throughout its life cycle. The expressed, implied or inferred attitudes of the stakeholders, individually and collectively, introduce 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 project 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 previously 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, form 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, a characteristic of the paradox in meta-thinking.

2.3 CRITERIA FOR DRAWING THE BOUNDARIES TO CAPTURE THE NECESSARY AND SUFFICIENT ELEMENTS OF INFLUENCE (GENERATORS OF COMPLEXITY)

The following criteria launch the methodology of this paper that portends to develop a new approach for analyzing complex systems. Five general features are identified from the aims of a Theory of Complexity (TOC) to inform the ultimate workings of a system that analyzes complexity in any field and thus in building construction:

1. **Prediction**: The search for predictive algorithms in nature that displays common features across many levels of disparate organizations. Complex situations are often soft and incorporate value systems that are abundant, different, and extremely difficult to observe or measure; thus, they may be better represented using nominal and interval scales.

2. **Control**: Awareness that delays to negative feedback loops increase the tendency for the system to oscillate, to become paradoxical or have paradoxical oscillations. Oscillation and instability reduce the ability to control for confounding variables and be able to discern cause and effect.

3. **Explanation**: A theoretical understanding and/or explanatory description of a system/framework for a number of phenomena; insights into the phenomena with natural language might be the main approach at uncovering knowledge.

4. **Aspiration for universality**: Applicable to a wide range of diverse phenomena; not necessarily linked to the discovery of a unifying theory.

5. **Unifying theory**: The coherent subject matter of complex systems science and the right level of abstractions at which its mechanisms and processes can be given a unified description.

Furthermore, the elements of influence must exhibit the following characteristics:

1. **Radical openness**: A feature internal to the ambience.
2. **Contextuality**: Senge (1994): (i) when the same action has dramatically different effects in both the short and long runs; (ii) when an action has one set of consequences locally and a different set of consequences in another part of the system or the meta-system or the ambience; (iii) when obvious interventions produce non-obvious consequences.

3. **Internal homogeneity**: Structural differentiation, increasing distinguishing non-trivial characteristics; Simon (1969): depends on whether the metaphors capture the real world and are significant or superficial.

4. **Adaptability**: A system in disequilibrium and evolving; self-modification in response to external forces (concepts of feedback and homeostasis) evolving over time, that is, they involve changing internal structure, changing external relationships to other systems, change with and/or by the ambience, and differential growth.

5. **Non-linearity**: No single optimum, too many variables. The past cannot be compared well to current circumstances. Unfamiliar or unintended feedback loops exist; many control parameters with potential interactions; indirect or inferential internal and external forces.

6. **Net-like causality**: The web of interconnections among disciplines, domains, and systems; the existence of multiple interacting feedback means it is difficult to hold other aspects of the system constant to isolate the effect of the variable of interest (many variables simultaneously change, confounding the interpretations). A number of natural systems characterized by not only intricate internal dynamics, but that also have the potential to interact with neighboring systems to the extent that it transforms and is transformed by them.

### 3.0 CONCLUSIONS

We have analyzed observed past and current studies as a point of departure for an inquiry into the nature of systems that could help describe the construction industry.

We focused on state of the art knowledge on ‘complexity’ because this is the key to understanding the boundaries of the systemic nature of building construction and the characteristics that we need to anticipate in our argument regarding how the elements of influence affect an exponentialoid. What we have found is that the worldviews which inform the manufacturing industry do not apply to the complexities found in construction. If this statement is accepted, then construction must have a different worldview.
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