How the Construction Industry does differ from manufacturing?

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This paper addresses the "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 obfuscating manufacturing-industrial-engineering mindset.

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.

Latham (1994) 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.

This paper using the state of the art research on the nature of the industry describes the intrinsic difference between the manufacturing and construction industries and lays the ground for a better understanding of the systemic nature of the industry.

Key Words: Adaptive Change, Panarchy, Paradigm, Philosophy, Systemic Nature of the Construction Industry, Theory

Introduction

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 (CMAR) to name a few, and application of technological and informational systems.

The reigning paradigm dictates that the construction 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, these efficiencies have not been achieved in construction. Why? There are several reasons to be considered: A simple answer to this may be that the part of construction moving off-site is the very efficient part (thus it is counted under manufacturing). So the construction industry is measured by all the on-site production, an intrinsically inefficient part. This shift has been going on for decades. Construction may be getting more efficient overall but it never shows in the statistics of "construction".

For the argument in this paper it has a broader consequence: construction has a diversity of sub-industries, some of which are morphing into manufacturing while others are constrained by socio-cultural movements of one of a kind. This uniqueness has allowed the architectural profession to promote expressiveness of built form as the great common good (over efficiency and repeatability). The latter is seen as having lower cultural value.

However we argue that perhaps the construction industry is radically different than manufacturing and thus the industrial paradigm is not the best fit. 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.

Invoking Philosophy in Construction Thinking

We need an understanding of the “why” as well as “how” construction occurs. The urgent problems connected with technology require philosophical clarification (Kuhn 1962; 2000; Eriksson 1997) since much that has been written about construction’s paradigm is inadequate (Ballard and Howell 2003) – making it all the more important for serious philosophers to get involved.

Koskela and Kagioglou (2006), show 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). Therefore we will address the construction paradigm issue, using logic, epistemology, metaphysics, and/or philosophical thinking to establish foundational knowledge concerning our discipline.

Two Metaphysical Worldviews: Entities and Becoming

The current worldview of an industry is based on increases in efficiencies that can be gradual, step or radical. Construction as an industry is expected to achieve the efficiencies of other industries, such as aircraft, shipbuilding, and automobile.

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), beginning with its peculiarities, characteristics and attributes. These studies highlighted the types and amount of anomalies in construction as an industry, comparing them with other industries in terms of efficiencies, cost reduction, innovation and lately, theory building.

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 and Vrijhoef (2001), in that the construction industry lacks its own body of theories, a quest that has led us to the First International Symposium on the Theory of the Built Environment 2007 in Salford, UK. The search for a theory for the construction industry may be closer to the metaphor alluded by Gunderson and Holling’s (2002) *Panarchy*: Adaptive Change, proposed for further studies.

The Systemic Nature of the Construction Industry

Two main aspects of construction 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 its “complexity.” Furthermore we postulate that the intertwined, dynamic, complex characteristics of building construction (Nam and Tatum 1988) is the arena where we can observe a paradoxical co-dependency of product (what is, being, entity, artifact) and process (what should be, becoming).

Models from Other Industries

The models of the aircraft, shipbuilding, automobile and other industries should have been sufficient to manage construction complexity 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. Academicians and some practitioners in the construction industry believe that theories and practices from one are translatable to the other. What prevent theoretical translation are differences in scale and differences in emphasis between product and processes.

Sam Grawe, (editor in chief of Dwell, a San Francisco-based magazine) compares construction with the automotive industry: “The reality of the situation is that for decades architects and even some builders have been aware of the inefficiencies of site-built, stick –built homes. The common analogy is whether you would feel comfortable hiring a random contractor to come and build your car in your driveway, leaving it exposed to the elements every night after he toes home and ordering every part piece by piece.” (FT 7/13/08).

Construction in general does not behave as an “industry,” but more like a “conglomerate of industries,” an “industry of industries,” a “meta-industry.” The meta-industry metaphor is used borrowing Palmer’s (2003, 2004) concept of meta-system which by definition 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, mainly because the subtle but real difference in scale and domains. This line of generic and structural thinking regarding complexity and the systemic nature of building construction as a meta-industry requires additional foundational work. We may look, in future work, at Gunderson and Holling (2002), *Panarchy* and the theories of adaptive change as a better fit for construction.

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*.”

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, Pearce 2006) or potential 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, and 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. Is this a semantic or a real distinction?

Groák (1992, 1994) 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.

Metaphysical basis for Distinctions between Product and Processes

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. They 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' (1898) second rule; 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" (Weick 2000). 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.

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 Figure 1). 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 1962).

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, 2002), 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; Baccarini 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 2005) 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 Figure 2). 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, potential, 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 Panarchy. In other words, the meta-systems nesting allow a high degree of inventiveness, promotes creativity, and celebrates diversity, adaptive change.

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 fundamental characteristics of building construction are those of a complex system, process driven with a normative capacity for change.

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.

Construction's reigning paradigm of being an "industry" does not quite capture the complexities embedded in the process of creating infrastructure and/or a building. 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.

Manufacturing and Construction are two different entities although there are manufactured products in construction and some of the processes such as those found in the airline and automobile industry are translatable to construction as in the Lean Construction Project Delivery System approach. However the essence of the nature of the construction industry as a meta-industry permeates its processes and products rendering a direct comparison of construction with the systemic nature of manufacturing not realistic.

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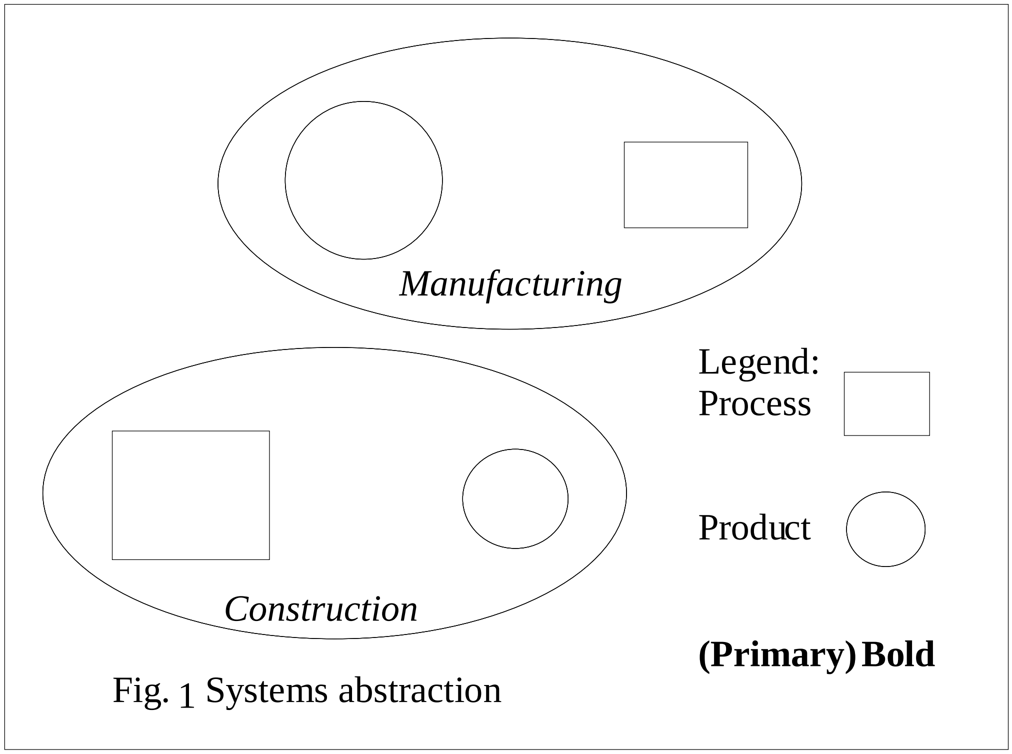

Fig. 1 Systems abstraction

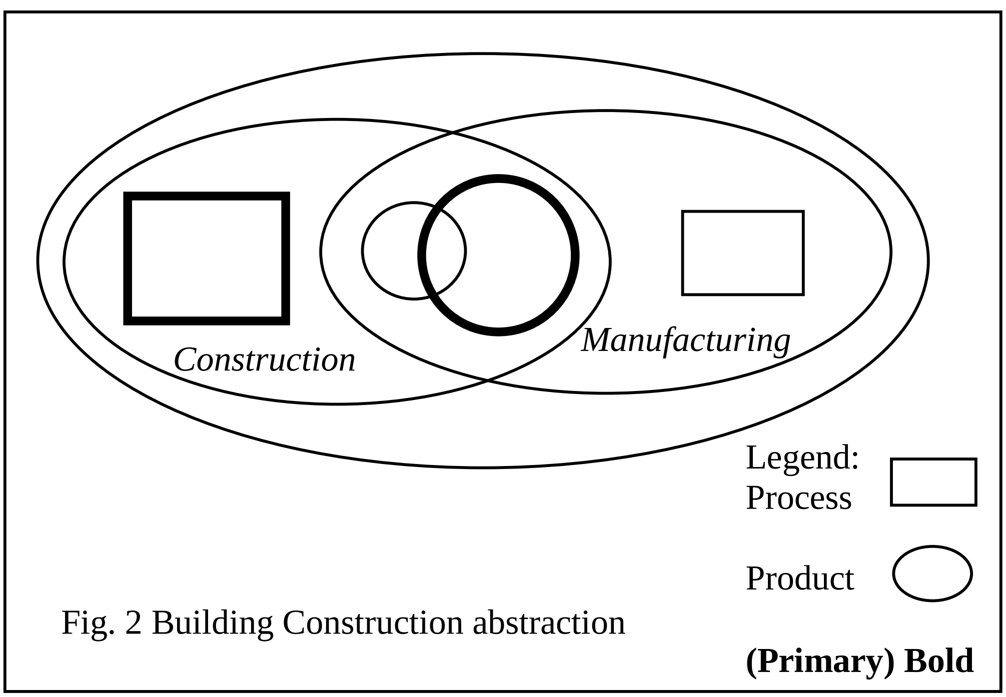

Fig. 2 Building Construction abstraction

Table 1 Complex Systems		
Koskela: Transformation Shingo: Operations	Value Value	Flow Process
1.1 Autonomous Agents	2.1 Undefined Values	3.1 Non-Linearity
1.2 Non Standard	2.2 Fitness Landscape	3.2 Emergence
1.3 Co-Evolution	2.3 Non-Uniform	3.3 Attractors
1.4 Self-Modification		3.4 Phase Changes
1.5 Downward Causation		3.5 Unpredictability
1.6 Self-reproduction		3.6 Instability (variability)
1.7 Mutability		3.7 Learning Organization

1.8 Fuzzy Functions

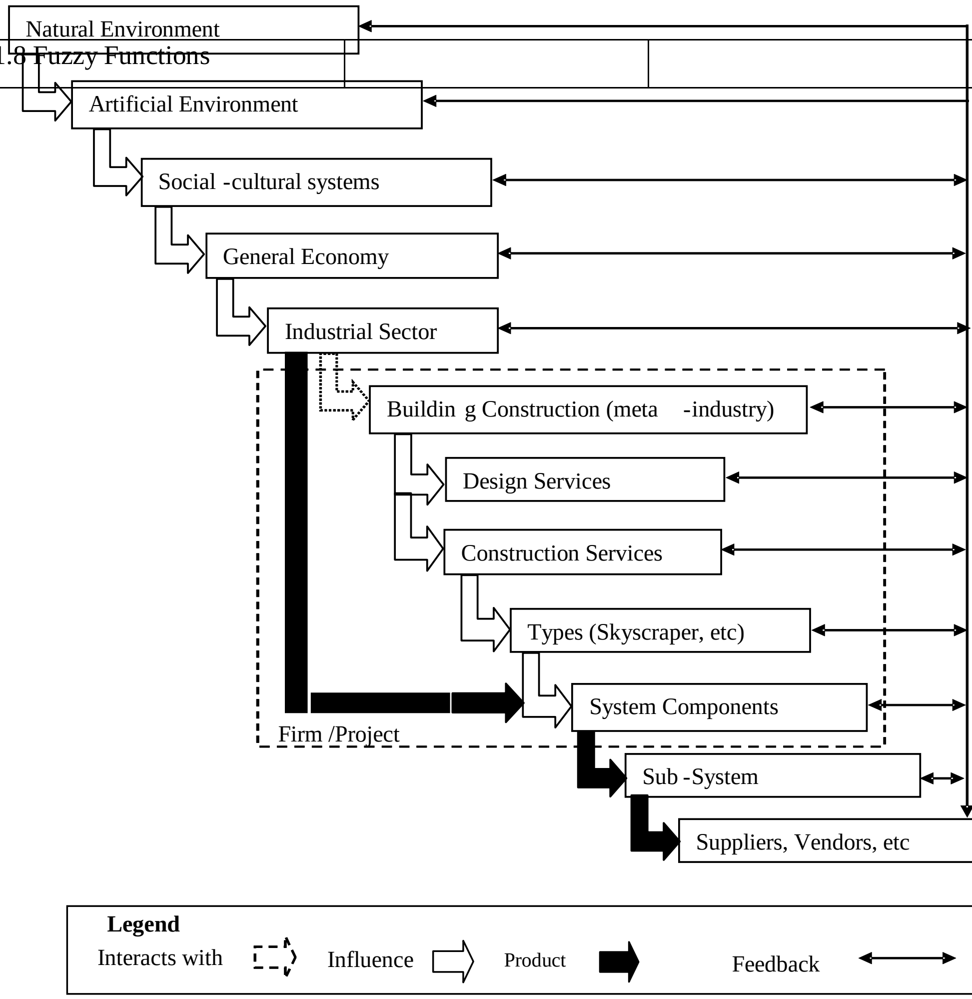

Fig. 3 Proposed General Taxonomy