The idealization of an integrated
BIM, Lean, and Green model (BLG)
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Extended Abstract

We are at a historical moment where increases in global population and economic affluence are creating exponentially greater resource consumption and a similar exponential increase in the generation of Greenhouse Gases (GhG). The construction industry is bracing for a prolonged inflationary period driven by rapidly expanding global demand and an urgent need to provide built environments that are sustainable in the long run. For the industry, the lack of idealization of futuristic solutions is a strong cultural and professional barrier; it also lacks a body of theory.

Efforts toward gaining efficiency through past initiatives have fallen short of expectations due to the systemic nature of the building industry. We argue that before we can embark on a quest for efficiency (are we doing the thing right?), we must first search for effectiveness (are we doing the right thing?). In other words, effectiveness is asking the right questions while efficiency is finding the right answers; effectiveness can be considered a philosophical, qualitative issue while efficiency is a scientific, quantitative one. A clear argument of the why (a la Kuhn 2000) needs to be articulated so that we know we are headed in the right direction (effective) before increasing speed (efficient).

How can the industry achieve consistent continual improvement in waste reduction, value creation, labor productivity increases, etc within the systemic nature of the construction industry with its unique defining characteristics?

The answer to the effectiveness question should come from the GREEN camp while the answer to the efficiency question should come from the LEAN set of practices. However, in order to make these answers reliable and predictable, we need to incorporate them into a platform such as Building Information Modeling (BIM) that can manipulate an immense amount of data and complexity and provide scenarios for stakeholders to buy-in.

BIM, an evolution from CAD, offers a platform for capturing lessons learned and the best practices of a LEAN Construction project delivery system. This is the closest that the industry comes to manufacturing without losing design prerogatives, in an envelope of “green” best practices that includes the concept of sustainability, as well as the reduction of both GhG emissions and the energy footprint. We call this new integrated platform BLG, an acronym for BIM, LEAN and GREEN.

BLG is the idealization of design and construction solutions in a total virtual environment, and it requires an understanding of the mechanism that makes it possible (technologies) and the protocols necessary to make it work. However, we must first conceptualize what BLG looks like and justify why it is needed. If BLG is to contribute significantly to the future, it

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must capture and make transparent all best practices in managing information, products, projects and processes as well as keeping track of energy related resources consumed (such as in transformation and flow), that is a total accountability of waste and value in the generation of a true model of future reality. This is where a BLG platform integrates BIM with LEAN and GREEN.

When looking at these concepts from a wider perspective, it becomes even more vital for all stakeholders to understand how these three knowledge domains can merge in one platform and capture the building’s service life. The increasing number of “GREEN initiatives” that deal with buildings after they have been constructed, such as LEED-EB (Existing Buildings), implies that Facility Management (FM) is considered at a similar level of importance as Architecture Engineering Construction (AEC). Lean construction’s concepts may be used for “LEAN maintenance” and “LEAN operation” of buildings. It can be seen that the BIM, LEAN and GREEN concept still has a long way to go from its current role in the design and construction phases to a wider role in the design, construction, operation and maintenance of buildings throughout their entire service life.

What makes BIM and LEAN practices financially possible is a shift in emphasis in the cost, time and quality project criteria. GREEN construction has become the premier motivator of shifting owner criteria from least cost, faster project to a high-performance project, when viewed in a Life Cycle Costing scenario. The implications of this shift from cost and time to quality are paradigmatic. The quest of achieving high-performance buildings (GREEN) has enlisted BIM technologies and applications and LEAN techniques and processes.

KEY WORDS
BLG (BIM, LEAN and GREEN), Building Information Modeling (BIM), Green, Idealization, Integration, Lean Construction, Road Map, Sustainability, Theory
1. Introduction

According to Garcia-Bacca (1963, 1989), an invention does not necessitate the next logical invention; that is, inventions and creativity are not predestined (Mitcham 1994). However, the fact remains that past inventions, innovations and technologies have created the current background of tools, knowledge and practices in the construction industry. In particular, the advent of Computer Aided Design (CAD) in two dimensions, then three dimensions, and now in $n^{th}$ dimension axiomatic design (Suh 2001) capabilities has improved the design aspects (Fowler 2003; Iansiti 1995). If Garcia-Bacca is correct, Building Information Modeling (BIM, defined as: 3D, object-oriented, Architect-Engineer-Contractor (AEC) specific CAD (Tang and Ogunlana 2003), or Building Product Modeling (Eastman 1999; Eastman et al. 2008), and now BIM-LEAN-GREEN (BLG), are not predestined from CAD by necessity but by human intentionality.

Because of the implications in handling variability and complexity, BIM and BLG have the potential to become industry wide paradigm shifts (Fernández-Solís 2007f). The import of this statement is that when implemented by a critical number of practitioners, the construction industry will be radically different from what we have in 2008; a paradigm shift (Kuhn 1962; 2000) will have occurred. What are the indicators that the ground is fertile for an industry wide paradigm shift?

1.1 Cost / Time / Quality Paradigm Shift

Project delivery systems are devised as solutions to construction’s changing needs. Design-bid-build (D-B-B) is a solution to cronyism and inflated costs that provided a mechanism to attain the least cost by a qualified service provider. When D-B-B least cost led to confrontation, change orders and litigation (supported by the Spearing Doctrine that documents have to be buildable and not a design intent), the industry created Design-build (DB), or a single contract agreement and project delivery system. Design-build allowed fast-tracking of projects and time (early completion) became another form of lowering cost by speeding up the moment when the capital asset becomes productive. Time, as a surrogate of cost, and lower cost has been the ruling paradigms even when selection processes emphasize Request for Qualification followed by a Request for Proposal. Construction Management at Risk and Integrated Project Delivery, are variants with time and cost as alternating main criteria.

Sustainability and the Green movement have shifted the project delivery main concern from cost and time to a high-performance project, that is, a shift toward a particular type of quality. This shift is a nascent paradigm shift in the industry, from cost and time of delivery to high-performance building. High performance is achieved not by fine-tuning component performance, but by looking at systemic performance, that is, the whole building performance. This requires an understanding of systems integration that is much more sophisticated than its appearance and common understanding dictates.

Therefore, it can be said that the driver of future construction, of project delivery systems will emphasize quality of design and execution toward the achievement of high performance in the areas of sustainability and the relationship of the built to the natural environment.

BIM and LEAN, by themselves, will have limited achievement outside this new GREEN paradigm. In other words, outside GREEN, the paradigm remains low cost or faster time to market and both BIM and LEAN strive to achieve those ends independently and concurrently. However, when BIM and LEAN are utilized in the context of achieving high-
performance building as required by a GREEN imperative, then the three have a synergistic potential, that of maximizing performance and not cost or time alone.

GREEN is the axis of effectiveness while LEAN and BIM compose the axis of efficiency.

1.2 Efficiency in Construction, a paradigm shift

Practitioners insinuate that we have achieved and can continue to achieve respectable construction efficiencies (Bowley 1966; Bennett et al. 1998a; Berger 2005; Bertelsen 2005; Forsberg et al.1996). 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 to achieve these efficiencies points to a lack of understanding of the systemic nature of the industry. Regarding productivity (Oglesby et al. 1989) in construction, US Labor Department statistics show that construction productivity has decreased over the last 40 years, while other industries have more than doubled their productivity (Fig. 1).

However, Rojas and Aramvareekul (2003) argue that the raw data used to calculate construction productivity values at the macroeconomic level and their further manipulation and interpretation present so many problems that the results should be deemed unreliable. “The uncertainty generated in the process of computing these values is such that it cannot be determined if labor productivity has actually increased, decreased, or remained constant in the construction industry for the 1979-1998 period.”

Furthermore, Rojas and Aramvareekul (2005) indicate that microeconomic studies suggest that labor productivity in construction may have actually increased in the above mentioned period. Construction trend in this period has favored moving elements that can be pre-assembled to off-site production. In this case, productivity gains are attributed to and accounted for by the manufacturing sector of the industry (Fisher 1993; Gann 1996), leaving the less productive tasks on-site, therefore biasing the construction data toward less labor productivity. While overall the construction process may have gained in productivity, the US Labor data continues to shows construction productivity as declining (Ranta 1993).

The US Labor data, if accepted as a valid indicator, portrays the construction industry as suffering from structural productivity problems that need to be corrected. According to Rittel and Webber (1973a, 1973b) and Teicholz (2004), the potential areas for improving productivity are:

- Use of IT/IS (BIM, which is also referred to as Visual Design and Construction - VDC)
- Project Delivery Systems (Lean Construction, Design-Build or Integrated PDS)
- Industry consolidation (fewer small firms, more large players)
- Increase R&D spending (currently it is less than 0.5%, while the average for all industries is 3.5%)

However, productivity efficiencies, in the absence of technological changes are dismal (Syben 1993). Proposals have been made to link design and automated construction (Howe 2000; Simon 1969; Tabatabai-Gargari and Elzarka 1998; Tang and Ogunlana 2003) with the automation of construction (Johnson 1995; Howe 2000), design and robotics (Warszawski 1990, Sangrey and Warszawski 1985). But others point out that construction, because of its nature and complexity (Waldrop 1992; Fernández-Solis 2007a; Gidado 1996), is between order and disorder at the boundaries of uncertainty and chaos (Bertelsen and Koskela 2002; Crichton 1996; Gleick 1987; Lewin 1993; Lorenz 1993; Scott 1933; Tavistock 1996; Thiétart and Forgues 1995). See Fig 2 where waste and variability are embedded and not obvious to the practitioner. The innate complex nature of construction (Sebestyén 1998) frustrates all current attempts at increasing its efficiencies in a systematic and predictable manner, like that evident in other industries such as manufacturing. Fernandez-Solis (2007e) argues that attempts at increasing efficiency add exterior complexity, with the paradoxical result of “sandbagging” efficiency improvement efforts.

![Fig.2. Conceptual boundary of the complexity of a construction project (Vanegas 2008)](image)

In Lean Construction thinking, local efficiency achievements are made at the expense of the whole project, a net result that may negate any local efficiency improvement. Systemic thinking is needed where local performance is fine tuned but not necessarily optimized, when considering the total project flow anchored on what constitutes final value for the client.

Other researchers have observed how far the construction industry needs to improve in the quest to become like manufacturing (Egan 1998; Fisher 1993; Fox et al. 2002a, 2002b; Gann 1996; Groák 1994; Miozzo and Ivory 2000; Syben1993; Strassman 1997). In this quest, some suggest that structural changes may be required (Koskela 2003a; Koskela and Kazi 2003) and argue that a theory of construction is needed (Koskela 2002; Whetten 1989), because the underlying theory of project management is obsolete (Koskela and Howell 2002a, 2002b; Lillran 1995). Furthermore, some question if construction, as currently practiced, is sustainable (Nootebom and Teisman 2003; see the seminal work of Pearce 2006 and Fernandez-Solis 2008). Construction productivity and efficiency is in what could be safely called an “identity crisis;” that is, it reflects the need to find a theory that can address internal and external complexity in the systemic nature of the industry (Seaden 2000; Seaden et al. 2000).
1.3 Pre-paradigmatic present (2008) conditions

The state of the art indicates that there is no single application (Sneed, quoted by Kuhn 2000) and there is definitely no single theory in the construction industry. However, Masterman, critiquing Kuhn, indicated that a paradigm “can function when the theory is not there,” in the case of the construction industry, and Kuhn (2000) agreed: “paradigm is what you use when the theory isn’t there.” In this sense, paradigm and heuristics are closely related and close descriptors of BLG as an idealized metaphor, at the present moment in time.

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; Koskela 1992) for clarity of ideas (we can infer direction such as what is effective) and then to science and technology for implementation (such as what is efficient), which underscores the purpose of this paper. According to Kuhn (1962, 1976), there are a few periods in history that deserve the label of “transforming eras,” during which circumstances changed sufficiently in response to challenges to warrant a major shift of assumptions in what he calls a paradigm shift. This transforming era paradigm shift occurs when people depend on working assumptions that become so inappropriate that they break down, to be replaced by a more appropriate set.

Likewise, building construction history is affected by internal and external forces that are characterized by long periods of stability in a paradigm, punctuated by relatively short periods of high instability (pre-paradigm shift or crisis). This exemplifies history as a staircase rather than a ramp (Kanter 1983). The current building construction industry crossroads, when considering the magnitude of the challenges, is at a historical pre-paradigm threshold, a time during which surmounting the crisis will require an exponential step. Again, what are the arguments underlying our position that we are at a pre-paradigmatic stage, on fertile ground toward a major paradigm shift of exponential consequences in the construction industry?

Previous advances in project management (Hillebrandt et al. 1974; Hofstede 1978) and in project delivery systems (Bertelsen and Koskela 2002; Briscoe et al. 2004; Parker and Oglesby 1972) have failed to deliver expected or projected efficiencies in a reliable and consistent way (Egbru 2004; Fernández-Solís 2007e; Gann 1996; Koskela and Vrijhoef 2001; Saxon 2002; Woudhuysen and Abley 2004). The quest can be stated as: How can the industry achieve consistent continual improvement in waste reduction, value creation, labor productivity increases, etc within the systemic nature of the construction industry with its unique defining characteristics?

Three independent forces, along with many others such as performance buildings (CIB 1997a; Foliente 2000) and studies revaluing construction (CIB 2005; CIB 2000, CIB 1997b; Miozzo and Ivory 2000), are currently working their way through the construction industry: BIM, Lean Construction and Green initiatives. Each is trying to affect or even change the paradigm that drives the industry. However we argue that:

1. Even if BIM, Lean and Green are practiced by individual firms and each initiative is practiced in isolation from the others, as in the current scenario, the necessary critical mass will not be realized and a significant industry wide paradigmatic change will not take place.

2. As multiple sources in the industry pursue BIM, Green, and Lean initiatives, there is an opportunity to integrate these initiatives through the understanding of their purposes and their philosophies.

3. A clear argument of the why needs to be articulated so that we know that we are headed in the right direction (effective) before increasing speed (efficient).
This investigation, a tour de force in literature search, establishes the state of the art research background about the long-term horizon of BIM, especially concerning the possibility of integrating BIM’s platform with Lean construction practices and with Green initiatives (BLG). Building Information Modeling (BIM) is at a starting point. In a parallel analogy with the state of the art from the 1960’s, BIM is at the slide rule level, when considering its future potential (even when it is not yet imagined because R&D investment is lacking for theoretical future studies) for addressing project complexities and variability while achieving effectiveness and efficiencies.

Internally, the envisioned BLG platform will capture the fundamentals of cooperation between these disciplines: direction about what to effectively adapt from GREEN, minimize waste, and increase value by increasing effectiveness (doing the right thing at the right time with the right team and equipment), a key tenet of LEAN initiatives in construction (Koskela et al. 2002, 2003; Koskela 1992, 2000, 2003b; Koskela and Ballard 2003; Koskela and Kagioglou 2006).

2. The Problem Statement

BIM is a concept that supports the interoperability (or generation), sharing, exchanging, and integration of information, among project stakeholders and possibly during the entire project lifecycle in a collaborative fashion. In this sense BIM is an idealization that simplifies the most crucial components of building in a three dimensional model with parametric attributes. BIM isolates the building components, which are defined by parameters, represents them visually, and assigns other values to the components. This visual set of representation are symbolic abstractions created and generated for construction product designs, and the purpose is to have a world characterization that should satisfy particular world-states (Mutis 2007; Mutis et al. 2007). BIM’s parametric attributes allow the building components not only to link to one another in a self awareness of time, space, and connectivity, but also with many more attributes that are not currently modeled, such as: (1) upstream: project financial pro-forma; site specific codes such as zoning, building and fire; geo-technical information and site historical data; (2) instream: tracking the entire process of fabrication transportation, storage and material placement; determination of sustainable, green product and system characteristics; (3) downstream: the life cycle of the building, including all aspects of maintenance, renovation and decommissioning (dematerialization or recycling).

Building Information Modelling (BIM) are technologies that employ the aforementioned parametric modelling in the design of construction building projects. The advantages of the technologies have motivated architects, owners, engineers, and other construction project stakeholders to evaluate the traditional methods of working with architectural designs. Multiple benefits have been attributed to the BIM technology such as early and more accurate visualizations, lower levels of design corrections, earlier collaborations with other disciplines, energy efficiency, and sustainability evaluations (Eastman et al. 2008; Krygiel et al. 2008; Kymmell 2008), among others. The problem is a lack of idealization of the future after BIM (Scharmer 2007). This is probably due to (1) the current focus on making BIM work, and (2) the lateness of CAD acceptance by construction companies, the most entrenched traditionalists of the service industries (Fitchen 1986; Groák, 1992, 1994; Latham 1998; Fernandez-Solis 2007e; Fox et al. 2002a; Koskela 2003a). Idealization is a critical tool in understanding processes, and as such, it is used mostly by architects, engineers and some constructors. There are three identifiable obstacles:
Companies need to stop using BIM as a marketing differentiation tool and start working toward the adoption and integration of BIM in the industry at all levels. Individuation and competition are major stumbling blocks to realizing efficiency potential and a higher industry-wide optimum. In the US, companies such as The Beck Group from Dallas, TX, and Linbeck from Houston, TX, have come to this conclusion and are devoting time and resources to reach out to the industry. Why? Perhaps when companies maximize themselves it is at the expense of systemic maximization, a Meta version of project Lean construction thinking, explained later.

Companies also have the difficulty of transitioning from using CAD, the traditional tool of individual and corporate visualization of a project, into using a systematic self-directed tool capable of doing everything typically done by general contractors. This is a stumbling block to making lessons learned permanent and applying them consistently in a virtual reality capable of generating multiple scenarios as a decision support system. The idealization itself is so real that it scares practitioners the way that CAD scared architects, causing them to think their profession would vanish and become a commodity rather than a personalized artistic service to the community, a guardian of the safety and welfare of society.

Companies should investigate using BIM, not on top of drawings and specifications and agreements (an addition to the current set of contract administration documents), but as the singular contract administration tool. When this takes place, BIM will have matured and achieved the same objective that CAD did when it replaced Mylar’s and layering by hand of the 1970’s.

Firms should understand that parametric models, such as BIM, are a family of propositions that constitute approximations that resemble instances or events of the world. A geometrical model of a construction beam, for example, does not reflect all sets of conditions of the world where the model is to be applied or used. The designer describes all the possible geometry and components within the geometrical model of the construction beam, adds additional attributes, and complements the model with documentation that specifies the required standards such as the material properties. The described components are simplifications of the complexity of the construction beam. However, the modelled components represent a novel tool that engages collaborative work to facilitate the understanding of the designs amongst project participant.

### 2.1 BIM and Project as a heuristic

Idealization, according to Wimsatt (2007) and Papert (2000), within the context of the philosophy of science, is a partial, multiple and plastic approximation based on heuristics, a precursor of theory, hypothesis and scientific research. Theories, Wimsatt argues, are the result of scientific reasoning, such as theories of complexity in construction (Fernández-Solís 2008; Baccarini 1996; Bertelsen 2003, 2004; Bertelsen and Emmitt 2005; Chu et. al 2003; Lucas 2000, 2004, 2005; Nightingale 2000), effectiveness and efficiencies (i.e. Lean Construction theories), and Green construction (sustainable theories).
Bayesian approaches are currently in vogue but many practicing scientists are more familiar with the Popperian model of the scientist as an ideal refutation engine that we shall examine later. Within all these models exists fallible, context-dependent heuristics, which are central to the success of science (Koen 2003). Therefore, a good model, one that idealizes reality, must focus on understanding construction and the use of heuristics. According to Koen (1985, 2003):

- 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.

What we are talking about is transferring the heuristics from all the stakeholders (strategic planning and especially those in tactical and implementation areas) into contract documents, now contained in a three-dimensional model, a model with the parameter of time, and a model with infinite number of parameters that not only encompass the product but the entire process, on its way to becoming a model that includes the entire life cycle of a project. Such a model remains an approximation at best (Sterman 2002), fallible and bounded in a messy complex ambient, that is organized around the idea of heuristics (how to best achieve effectiveness and efficiency), that is, to minimize waste in the transformation and flow, and create value for the owner and stakeholders. What is gained in BIM and BLG platforms is the reduction of the search time for anticipating and solving problems.

2.2 Project as an experiment testing the design hypothesis

Traditionally in a project, the design can be idealized as a hypothesis, construction as the experiment that tests the hypothesis, and performance as the comparison between what was intended and the test results when the project is completed (Kohler and Hassler 2002). The idea of viewing aspects of a project as a hypothesis and the construction as an experiment is not new. For example, the project has been idealized as an economic hypothesis (Carassus 1998, 1999; Hillebrandt 1974). BLG introduces the option of a virtual building hypothesis that encompasses finance, sustainability, construction, operation and maintenance, which can all be manipulated to obtain the local optimum of the project before testing it through actual construction (see Fig. 3).

<table>
<thead>
<tr>
<th>Traditional</th>
<th>= Hypothesis</th>
</tr>
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<tbody>
<tr>
<td>Design + Constructability</td>
<td>Construct = Experiment testing the hypothesis</td>
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<table>
<thead>
<tr>
<th>BLG</th>
<th>= Local optimum hypothesis model and testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design + Constructability</td>
<td>BLG - Heuristics = Experiment testing the hypothesis</td>
</tr>
</tbody>
</table>

Fig. 3 Project as a theory

The possibility of finding a local optimum through a virtual project that encompasses not only the design but also the production, benchmarked best practices (as in Lean Construction thinking), and best practices in green building, with a holistic understanding of sustainability and emissions generation, is a step to capture suggested waste in the industry (Hillebrandt
1974, 1975, 1984). What is the magnitude of this waste? Lean Construction claims that all construction related waste in a typical project approximates 50%. The Beck Group in a white paper in 2000 identified readily available construction waste to be approximately 27%. There are multiple attempts at capturing this waste and converting it into value for the owner, one of which is Lean Construction.

Waste reduction (Coventry and Guthrie 1999) and value generation are the landmarks of Lean Construction (Howell and Ballard 1994a, 1994b, 1997; Howell et al. 1993a, 1993b; Howell and Koskela 2000) and the holy grail of the construction industry (Allen 1985). It is estimated that changing project delivery systems would reach significant reduction in waste, such as going from the litigious, but least cost by a qualified service Design-Bid-Build (DBB) to Design-Build (D-B), with all its variations, and Construction Management at Risk (CM@R), with fast-tracking potential, ultimately cost related (Cox and Townsend 1998). None of the project delivery systems have achieved efficiencies consistently, that is, in a predictable, repeatable and reliable way.

However D-B has generated an average 5% improvement over DBB. Integrating project delivery in a virtual organization (Lundin and Söderholm 1995; Lundin and Steinthórsson 2003; Eccles 1981) of all stakeholders with the use of Project Definition Rating Index (PDRI) (Durmont, et al. 1997; Cho, et al. 1999), Partnering (Baden 1995; Bennett and Jayes 1998b; Larson, 1995; Godfrey, 1996; Rackman et al. 1996), and a plethora of other initiatives in a D-B type of agreement reaches at best, an additional 5% efficiency increase. However, this is sporadic and depends on the project type, team and all the customary variables. See Table 2 for a heuristic posed for future research verification.

<table>
<thead>
<tr>
<th>Project Delivery System</th>
<th>Minimum</th>
<th>Maximum</th>
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<tbody>
<tr>
<td>Design–Bid–Build (DBB)</td>
<td>Base-line</td>
<td>Base-line</td>
</tr>
<tr>
<td>Design-Build (DB)</td>
<td>0 %</td>
<td>5 %</td>
</tr>
<tr>
<td>Construction Management at Risk (CMAR)</td>
<td>5 %</td>
<td>10%</td>
</tr>
<tr>
<td>Integrated (Virtual Organizations)</td>
<td>10%</td>
<td>15%</td>
</tr>
<tr>
<td>Lean Construction (individual)</td>
<td>15%</td>
<td>20%</td>
</tr>
<tr>
<td>Lean Construction (regional)</td>
<td>20%</td>
<td>35%</td>
</tr>
<tr>
<td>BLG (Individual)</td>
<td>25%</td>
<td>40%</td>
</tr>
<tr>
<td>BLG (Regional)</td>
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</table>

Table 2. Value Opportunities range to minimize waste and maximize value in Construction based on heuristics

Lean construction (Alarcón 1997; Ballard and Howell 1994; 1998a; 1998b), adapted to the peculiarities of construction, has benchmarked best practices from the manufacturing industry with the concepts of transformation, flow and value, waste minimization and value maximization, pull techniques (Ballard 1999), last planner (Ballard 1994; 2000; Ballard and Howell 2003b), lean project management (Ballard and Howell 2003c). This has brought another possible 5% improvement to the project delivery (Ballard and Howell 2003a; 2004; Ballard et al 2002; Ballard 2005).

However, a glass efficiency ceiling has been reached because companies are doing LC individually, but the industry has not caught on downstream: some companies do it one way, other companies do it another, and the majority, a large number of very small companies, do not practice LC in any way (Abdelhamid 2004). If the industry at large were to implement LC, an estimated 20% waste elimination / value generation would be reached—a hypothesis to
be tested. However, with a BLG platform, first at the individual company level, a 25% waste elimination and value generation is hypothesized, and if the industry at large adopts a BLG platform, the probable local optimum of 40% could be reached in a consistent and predictable way, using DBB as a benchmark. In other words, the current paradigm is about company differentiation and a lack of systemic thinking of the industry as a whole, a kind of company maximization at the expense of industrial efficiency. This type of critical thinking parallels Lean Construction observation that maximizing a part or a process is done at the expense of the whole. To achieve waste minimization and the levels of value creation, the industry needs to have meta-systemic thinking.

2.3 Lack of meta-systemic thinking at the industry level

The construction industry at large has no clear understanding of the difference between effectiveness (doing the right thing, the why, a philosophical and qualitative question) and efficiency (doing the thing better, continual improvement, change, a quantitative issue). Without a clear understanding of the nuances implied by effectiveness and efficiency, the industry could be moving faster on the train of change, but in the wrong direction. Effectiveness and efficiency are the two attributes (two sides of the same coin, the vectorial elements with an emphasis first on the direction, the why and then the magnitude – the origin is taken for granted). Lack of an understanding of the problem, has led to the current state of a multitude of improvement initiatives with increased complexity in the project delivery process and with decreasing results such as:

- **Organization related:**
  - Project Management (Miozzo and Ivory, 2000; PMI 1999);
  - Project Management Body of Knowledge (PMI 2000);
  - Partnering (Baden 1995; Bennett and Jayes 1998b; Godfrey 1996; Rackman et al. 1996; Slaughter 1998);
  - Project Definition Rating Index, (PDRI™) (Cho, et al. 1999; Durmont, et al. 1997);
  - Learning Organizations (Edmondson and Moingeon 1998);
  - Knowledge Management (COM 2000);
  - Open Building (Kendall and Teicher 2000; Van der Werf 1990; Vrijhoef et al. 2002);
  - Virtual Organization (Winch 1998);
  - Comparison with other industries (Vrijhoef and Koskela 2005a, 2005b, 2005c; Voodijk and Vrijhoef 2003);
  - Emergent Change (Weick 2000)

- **Performance related:**
  - Total Building Commissioning (USGSA, 1998; NIBS 1999);
  - Lean Construction (Alarcon 1997; Ballard and Howell 1994; Santos, 1999; Howell, and Koskela 2000; Ballard et al. 2002; Koskela et al. 2002; Vrijhoef et al. 2002);
  - Concurrent Engineering and Fast Tracking (Ballard, G., 1999);
  - Just in Time Production (JIT) (Gilbreths and Gilbreth 1922; Hopp and Spearman, 1996);
  - Total Quality Management (Shewhart 1931; Shewhart and Deming 1939);
  - Continuous Improvement Theories (Wortmann et al. 1997);
  - Theories of Integration (Wortmann 1992a; 1992b);
  - Robotics (Sangrey and Warszawski 1985; Warszawski 1990);
• Re-Engineering (Winch 2003);
• Last Planner (Ballard 1994; 2000; Ballard and Howell 2003b);
• Constructability and Buildability (Ferguson 1989; O’Connor 1986; Shin 1992)
• Value Engineering and Management(Kohler 2006; Allen 1996);
• Life Cycle Costing
• Critical Path Scheduling

• IT related:
  • Digital Building Process and As-built Documents (Tabatabai-Gargari and Elzarka 1998)

• Codes and Standards related:
  • Performance Based Building Codes, Standards and Specifications (Foliente 2000)

• Contract and Structure related:
  • Integrated Project Delivery Systems (such as: Design-Build and similar variations) Bowley, 1966; Bennet et al. 1996;
  • Construction Management @ Risk and multiple variations;
  • Subcontractors and Vendors Alliances (Cox and Townsend 1998; Pyke, 2002).

• Environmentally related:
  • LEED® (US Green Building Council)
  • SPiRit (US Army)
  • Green Globes (USA)
  • BREAM™
  • GBTool™ (UK)
  • BASIX (Australian)
  • Green Star (Australia)
  • HQE²R (CSTB - France)
  • CASBEE (BEE Japan)

Each of the above listed initiatives was created in response to an identified problem. However, these individual and collective initiatives have increased project delivery complexity, failed to achieve a permanent, reliable, consistent increase in efficiency and have come up short in providing an answer to the original question: *How can the industry achieve consistent continual improvement in waste reduction, value creation, labor productivity increases, etc within the systemic nature of the construction industry with its unique defining characteristics?*

2.4 Proliferation of initiatives without corresponding efficiency synergy

Koskela et al. (2003) developed, or elucidated, the issues surrounding increasing complexity of the proposed trends and initiatives without significant results, which brings to mind Kuhn’s (1976) statement:

“When complexity increases far more rapidly than its accuracy or benefit and that a discrepancy corrected in one place is likely to show up in another may lead to a similar proclamation as that of Alfonso X that if God had consulted him when creating the universe, he would have received good advice, or Copernicus comment in *De Revolutionibus* that the astronomical tradition he
inherited had finally created only a monster.” “Proliferation of versions of theories is a very usual symptom (or concomitant) of crisis.”

The crisis is a lack of focus on effectiveness, a proliferation of efficiency techniques that complicate and exponentially increase the complexity, resulting in a dramatic decrease in efficiency, exactly the opposite of its intent.

A literature search indicates an obsession with change in the industry towards achieving greater efficiencies (Dubois and Gadde 2002; Egan 2002), as in manufacturing. However, first we must ask the question: Is what we are doing effective (the correct thing to do – environmental, sustainable (with the right paradigm, waste reduction value generation, etc) and then we can ask: are we doing ‘it’ efficiently (doing the thing right (least cost, fastest, better quality) (Fairclough 2002; Atkin 1999; Pries and Janssen 1995; Pries at al. 2004; ) within the systemic nature of the construction industry (Nam and Tatum 1988).

3.0 Separate Knowledge Domains

BIM, LEAN construction practices and GREEN, or sustainable, eco-friendly initiatives are typically taught, practiced and thought of as separate knowledge domains. There is a project for an owner for which different disciplines assign management teams, to which we now add LEED certification requirements along with partnering, PDRI and commissioning requirements, and ask that Lean construction practices be implemented using CAD 3d or nD models et al. It is also possible to have other dimensions associated with the construction products designs that have their own definition and set of constraints and rules. Our research embraces Green and LEAN™concepts by associating them with additional dimensions in the design of a construction product. We argue that in the near future we will have an integration of LEAN and GREEN initiatives centered on a BIM platform due to the continued improvement in processing capabilities, increased bandwidth and an industry need to achieve higher levels of efficiencies and effectiveness in a consistent and predictable manner. The capabilities of a BLG platform are showcased in a future scenario based on current technologies and practices.

Following the established logic that we first need to identify the “effective why” and then the “efficient how” we propose that: GREEN should provide the effective reasoning behind the “why” we need to do things differently, LEAN provides the body of knowledge, the “how” the intended levels of efficiency can be modeled, and BIM is the platform that captures the why and how in a consistent, predictable virtual reality that allows scenario playing until the stakeholders buy into the proposed strategic action plan along with its tactical controls and feedback loops.

3.1 GREEN - Effectiveness

The Bruntland Report (WCED 1987) provides a mission statement focusing on sustainability but does not elaborate a vision on how to get there. A working definition of sustainability by Fernández-Solis (2008) is proposed whereby sustainability is the force that tames an exponential growth. This definition offers a more concrete direction toward establishing metrics that can be translated into objectives, strategic planning and tactical execution, that is, how to tame an exponential growth (resource consumption, emissions generation, etc). However, a deeper philosophical understanding of the problem is necessary. In short, everything that we create solves a problem but, according to the Popper (1959, 1972) method
of conjecture and refutation, also creates a problem. See Fig. 5, where $P_1$ is the original problem, $TT_1$ is a tentative solution and $EE_1$ is the error elimination but the result is $P_2$, a new problem.

![Fig. 5. Popper’s (1972) Analytical Process of Conjectures and Refutations](image)

For example, the automobile solved the problems of distance and speed limitations of the horse and buggy by adding speed and range, but it created new problems: roads, service centers, etc. Success in individualized transportation created a very large number of vehicles in operation--in the short term, they are a benefit to the economy. Those numbers are increasing exponentially in the global market: one car per person in this six, going on nine, billion people on planet Earth is not a viable option and cannot be sustained in the long term. A new paradigm is needed where everything that is proposed needs to be both scalable (from micro to mezzo to macro numbers; it must be able to grow without creating new, bigger problems) and sustained in time from short term to medium to long term horizons (the growth can be projected into the future without causing a new, bigger problem). See Fig. 6 and Fernández-Solís (2008).

![Fig. 6 Scales of number in a time line (Fernandez-Solis 2007)](image)

Sustainability is the application of this new paradigm that filters how we see the ultimate consequence of our actions in numbers (scales), and times, which is the same as space (matter, scales) and time (continuum) the two constitutive characteristics of the universe Hawkin 1996). Sustainability needs to be scalable and sustainable in time, over the long term; therefore sustainability must be effective (doing the right thing) before it is efficient (doing the thing right). GREEN is the movement towards sustainable construction in the sense that unbridled resource consumption and ever increasing emissions generation need to be tamed. That is the exponential growth rate needing to be tamed in order to create a way of life that can be sustained in the long term and at ever increasing scales (Fernández-Solís 2007a).

BLG is then a platform that captures this paradigm of scale and time and filters all aspects of construction through a philosophical construct with the hope that the problems we are
solving are not creating even bigger problems... our current predicament. The primordial aspects of the universe are space and time, and space and time are also the critical elements of construction. In a virtual model, BLG captures, by its own nature, the changing possibilities of space and time, with all of their intrinsic complexity, until an optimal change pattern (of materials and processes) is agreed upon for implementation by the stakeholders.

Sustainability initiatives follow the Rene Descartes’ dictum, which is also known as the environmental precautionary principle: “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” (Descartes, quoted by Koen 2003). We propose that all Green and sustainable initiatives should be viewed and scrutinized under the aforementioned new paradigm of scales and time. Can the proposed practice be scaled up in very large numbers and at the same time be carried out continuously on a long term horizon? Passing this litmus test indicates that we are doing the right thing according to the state of the art science and that, according to Popper’s Theory of Conjecture and Refutations, we anticipate problem solutions that do not create a bigger problem, that is, when the solutions are effective.

3.2 LEAN - Efficiency

The process of constructing a building uses separate strategic and tactical approaches. That is, one strategic approach for planning and another tactical approach is used for executing. LEAN Construction™ employs a set of techniques borrowed and adapted from manufacturing in order to address the complexity and peculiarities of the industry (Fernandez-Solis 2008). It looks at the execution to better inform the planning among other tools such as Lean Construction (LC), Critical Path Method (CPM, Last Planner System (LPS), and Just in Time (JIT) movements, among others. To increase efficiency, Project Delivery Systems have been created, such as Design-Bid-Build (DBB); Design-Build (DB); Construction Manager at Risk (CM@R) and Lean PDS, among others.

Lean is based on specific values that an owner establishes. To achieve this, the project stakeholders need specific product, capabilities, price and time data, all items that a BIM platform can readily provide. From the owner’s side, a project can be design-specific or performance-specific, because from the manufacturing side, the products have design-specific information as well as performance-specifications. We envision that all items of a project will be bar coded using FIATECH (2004) protocols of information that have embedded in the bar code both design and performance specifications. BLG will embed the information that LEAN requires to:

1. Maintain a value stream with a capacity to rapidly prototype scenarios to
2. Achieve and maintain continuous flow in a
3. Pull ambient while
4. Striving for perfection

Both kaikazu (radical improvements, Gann 1996) as well as kaizen (continuous incremental improvements, Imai 1986) can be rapidly prototyped within the BLG model. Pull scenarios can be played within a decision support matrix that evaluates the local optimum for the project (Fernandez-Solis 2008).

3.3 BIM – Hypothesis experiment and virtual project (experiment) testing

BIM is a collaborative approach that produces a sophisticated digital model of a building which is linked to a database of information on all aspects of its design and components. The building construction industry, governments, owners and other stakeholders in capital
creation through construction have identified BIM as an accelerated technological initiative (FIATECH 2004), leading to an increase in efficiencies and effectiveness.

BIM is expected to help practitioners in the AEC industry achieve higher levels of efficiency (by doing things right, Emerson 1917), generate and exchange information, create digital representations of all stages of the building process, and simulate real world performance. BIM, as a concept, demands intensive collaborative efforts, and its purpose is to overcome inefficiencies produced by disruptions in construction activities when multiple actors interoperate (Butler 2002). However, BIM represents imaginary situations created by designers. These situations have to be understood by other actors, and they cannot be characterized all context conditions during all the stages of the project within a formal representation. Situations map perceived conditions of states of affairs of the world or map assumed conditions of the designer’s imaginary world. In imaginary domains, such as the design creations, the characterizations’ situations are extremely complex to represent. They are only possible through the use of poor metaphors that are created or assembled from representations (Mutis 2007). The use of templates and rules for describing situations are poor descriptions of the complexity of the states of affairs because of the situation’s incommensurability nature.

At a deeper philosophical level, the adoption of BIM by the construction community implies the orientation of the rationalistic tradition that regards systems of representation as patterns that stand for things in the world. Architecture as a design discipline has embraced CAD in two, three, and now multiple dimensions. The advent of 3D and now nD (the possibility of infinite number of dimensions in modeling) has generated real interest in the construction sector of the industry (FIATCH 2004; Johnson 1995; Tabatabai-Gargari and Elzarka 1998; Tang and Ogunlana 2003). The construction industry’s needs are different and require tracking an ever increasing number of parameters in a robust platform that can operate with suppliers, vendors and the entire organization of a construction firm. Both design 3D modeling and BIM require an inordinate amount of computing power that recently has become available and is cost effective, due to Moore’s laws, the logarithmic increase in transistors, data storage capacity, the advent and availability of software interoperability and access to increasing internet bandwidth.

4.0 Global push

We are at a historical moment where increases in global population and affluence (Von Weiszäcker et al. 2007; Varon 1975) are creating an exponential demand on resources (Barnett and Morse 1963; Barnett 1979; Strassman 1988) and an equal exponential increase in the generation of Greenhouse Gases (GhG) (Fernandez-Solis 2007b). The construction industry is bracing for a prolonged inflationary period. Business as usual in the construction sector will not be possible in the near future.

However, unless the best of our understanding of what it takes to be sustainable and the best practices for delivering projects are integrated with a platform that can provide reliable construction practices, savings and efficiencies, the goals of the individual, BIM, LEAN and GREEN will not be achieved to their full capacities. The basic premise of this paper is that it takes an integration of all three to create the synergies required to tame the exponential growth in resource consumption, emissions generation and inflationary forces.
5.0 The problem conclusions

BLG™ marries a technology with promise that has caught the interest of the construction industry (albeit a technology in its infancy and an interest at an individual company level) with the transference of manufacturing best practices in Lean Construction™ (albeit with limited results because of the individual company scale of implementation). These are combined with green sustainable initiatives and benchmarked systems of best practices that promise a reduced energy and material footprint along with quality and performance improvements (albeit in its early stages).

When looking at these concepts from a wider perspective, it becomes even more vital to understand how these three knowledge domains can merge throughout the building’s service life. The increasing number of “Green initiatives” that deal with buildings after they have been constructed, such as LEED-EB, implies that facility management is considered at a similar level of importance as AEC. BIM itself still must be studied to figure out the benefits of utilizing it for post-occupancy phases, rather than merely for design and construction, as it is used today. Also, Lean construction’s concepts may be used for “LEAN maintenance” and “LEAN operation” of buildings. It can be seen that BLG still has a long way to go from its current role in the design and construction phases to a wider role in the design, construction, and operation of buildings throughout their entire service life.

The employment of parametric models in BIM, to perform simulations of energy consumption is a practical strategy that significantly supports designers in optimizing their architectural designs and the material selection for their creations. LEAN Construction™ proposes an alternative for minimizing waste while maximizing value in the transformation of prime matter into objects and eventually projects, and in minimizing waste in the production understood as a flow. This alternative leads to a reflection of a re-conceptualization of construction products and processes which require an understanding of the embedded energies in both product and process.

Currently we have parts and pieces of embedded energies, but not to the level necessary to create a correct, complete and timely accountability of a building footprint (Wackernagel et al. 1997; 2002; Venetoulis and Talberth 2005; Van Vuuren. and Bouwman 2005) that could be used for benchmarking and establishing an energy economy (Pearce 1989; 2003; Pearce and Turner 1990; Pearce et al. 1989; Pearce and Warford 1993) where value is based on building performance. The employment of parametric models in BLG to perform simulations of energy consumption is a practical strategy that significantly supports designers in optimizing their architectural designs and the materials of their creations.

Regarding GREEN, we have a rudimentary sustainability mission statement, and an early understanding of embedded energies. However we do not have at this time the necessary information to create a correct, complete and timely accountability of a building footprint that could be used for benchmarking and establishing an energy economy, where value is based on a building energy footprint and achieving increasingly exigent performance requirements.

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