SYSTEM VIEW OF LEAN CONSTRUCTION APPLICATION OPPORTUNITIES

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ABSTRACT

Construction has been one of the first sectors to discuss Lean Thinking in an environment different from that where it was developed. Lean Thinking is a broad concept and construction is a highly diversified and complex sector, so the opportunities for application are very wide. This paper will discuss these opportunities in a systematic framework, useful for identifying interactions among applications developed so far as well as gaps for future studies.

This framework will be constructed crossing Lean Thinking core elements and construction main flows. Due to differences between construction and manufacturing, lean tools direct application is not suitable in most cases. Lean principles deployed to a detailed conceptual level, named core elements, is argued to be a better basis for the discussion of potential applications in different environments, as construction. According to lean concept, construction is understood in this paper as a connection of five main flows. The discussion of each core element for each flow points up opportunities of application.

KEY WORDS

Lean construction, applications, system view.

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INTRODUCTION

Lean Thinking is a concept based on the Toyota Production System (TPS), consequently developed in a manufacturing environment, more specifically in the automotive industry. Since Womack, Jones, and Roos (1990) announced this concept as a new production paradigm, several industries have dedicated great attention to the possibilities of applications to their environments.

Construction is a very complex sector, with many differences from manufacturing. Since Koskela's pioneer report (Koskela, 1992), several researchers and industry practitioners have sought concept interpretation (e.g. Howell and Koskela, 2000; Howell, 1999, Ballard and Howell, 1998) and practical application. A large number of discussions and cases can be found in the International Group for Lean Construction (IGLC) Conference papers[2], dealing with different issues, such as design, suppliers, job site, etc.

A system view understanding of concepts and experiences accumulated so far is the harder challenge for companies from any industry, in the lean transformation. Lean Thinking is a complex combination of philosophy, system and techniques, and a misunderstanding of this combination, for example focusing on isolated techniques (or tools), is one of the most common reason for poor partial implementations with few results.

This paper presents a proposal of a framework that aims to enable a systematic discussion of opportunities of lean thinking application to the construction sector. The system view provided by this discussion is useful for understanding the complex links that exist among lean concepts, techniques, and cases applied to the construction so far, as well as for the identification of gaps and future priorities.

PROPOSED FRAMEWORK FOR A SYSTEM VIEW

THE FIRST DIMENSION: LEAN THINKING COMPLEXITY REPRESENTATION

Waste elimination is the basis of Lean Thinking, as stated in the TPS definition referred by Liker (1997, p.7): "a manufacturing philosophy that shortens the time line between the customer order and shipment by eliminating waste." For this purpose, several techniques (or tools) have been developed, directly related to Lean Thinking.

The term "techniques" (or tools) is generally used for routines, standardized for training and communication, such as Kanban, Total Productive Maintenance (TPM), 5S, Poka-yoke, etc[3]. These techniques are the most visible components, and sometimes are misunderstood, being confused with the whole system. Shingo (1989, p. 67) says that most people answer that "TPS is Kanban," but in his opinion TPS is just 5% Kanban, (that is a means of achieving Just In Time), 15% production system, and 80% waste elimination.

The understanding of the philosophy and system that are behind these techniques is fundamental: "Lean manufacturing includes a set of techniques that comprise a system that derives from a philosophy" (Shook, 1997, pg 45). We can say that techniques are more related to operational aspects, system to integration aspects, and philosophy to conceptual aspects (Table 1). In truth, the separation of technique/system/philosophy is not simple. Every technique (Kanban, for example), when taught, is integrated to the system (e.g. the JIT production system) and several conceptual aspects, or philosophy, are emphasized (pulled production, total quality, etc.).

[2] Available in Alarcon (1997) and at IGLC site: http://cic.vtt.fi/lean/conferences.htm.

[3] These and other techniques are described in the literature, e.g.: Shingo (1989), Monden (1998), Schomberger (1982), Suzaki (1987).

Table 1 – Lean Thinking: Philosophy, system, and techniques

Level	*Aspects*	*Focus*	*Aspects*	*Adaptation demanded*
Philosophy	Conceptual	Permanent goals	**Conceptual ⇒ ⇐ Operational**	**Less ⇒ ⇐ More**
System	Coordination aspects	How techniques are integrated, coherently with philosophy		
Techniques	Operational	How to put the philosophy in practice		

The philosophy behind systems and techniques is the most important element. It is very difficult to be described since it is composed by objectives and concepts not always explicit. In TPS the subtle philosophy is transmitted day-by-day to employees and is present in all operational techniques.

Besides a conceptual basis provided by philosophy, a company needs practical application templates, in the operational level, to design its systems and select techniques. The direct application of techniques developed in an industry to a different sector is limited, due to specific characteristics of each industry (as stated by Koskela and Vrijhoef 2000). In this case, more adaptation is demanded in the operational extreme (techniques) and less in the conceptual extreme (philosophy). In the framework proposed we subordinate the techniques' understanding, selection, and adaptation to a deployed concept analysis. We named this deployed concepts as "lean core elements," discussed below.

THE SECOND DIMENSION: CONSTRUCTION SECTOR COMPLEXITY REPRESENTATION

Construction is a very complex sector, with strong fragmentation. In the product cycle several companies are involved, such as owners, designers, general contractor, sub-contractors, suppliers. Lean thinking proposes that the enterprise should be analysed through their flows (from order to cash, from raw materials to delivery, etc.), and not through departments.

The construction project can be understood as a virtual, multi-company and temporary organization. The application of lean thinking application opportunities, if limited to each company involved, will not focus on the major potential of waste reduction, considering the whole flows within the project. For this reason, the construction main flows, discussed below, are the second dimension of the proposed framework.

CROSSING LEAN CORE ELEMENTS AND CONSTRUCTION FLOWS

We propose as a framework for a systematic analysis of lean thinking opportunities[4] for the construction sector a matrix, crossing the lean core elements and the construction flows, as discussed above and detailed in the following sections.

This framework's objective is to provide a system view to help construction sector agents to design their system and select, adapt or create techniques coherent with lean philosophy. Identifying techniques and showing how they are integrated in the "lean core elements x flows" framework is a way to give meaning and context to these techniques.

[4] "Opportunities for application" or just "opportunities" are referred in this work as possible applications of lean concepts or techniques to the construction sector , with interesting expected results.

LEAN CORE ELEMENTS

The inexplicit way lean philosophy, system and techniques have been developed and transmitted in Toyota becomes a difficulty for other companies and industries to understand its core elements and try to implement them. Several authors, from outside, have studied the system, providing descriptions more focused on the system and its techniques, such as .: Shingo (1989), Monden (1998), Schomberger (1982), Suzaki (1987)

The most recent efforts to understand the core elements are provided by Womack and Jones (1996), Spear and Bowen (1999) and Fujimoto (1999).

WOMACK AND JONES'S 5 PRINCIPLES

Womack and Jones (1996) organize the fundaments of Lean Thinking in five principles:

- **Value**: specify and enhance value
- **Value Stream**: identify the value stream and remove waste
- **Flow**: make the product flow
- **Pull**: let the customer pull
- **Perfection**: manage toward perfection

Actually, these principles go beyond the Production System practiced up to now by Toyota, emphasizing for example aspects in the principles "Value" and "Value Stream" towards a vision of a wide application in the whole and extended company.

SPEAR AND BOWEN'S 4 RULES

Spear and Bowen (1999) state that the tacit knowledge that underlines TPS can be captured in four basic rules:

- **Work**: shall be highly specified as to content, sequence, timing, outcome;
- **Connections:** all communications must be direct and unambiguous;
- **Pathways**: for every product and service must be simple and direct;
- **Improvements**: must be made using a scientific method at the lowest level in the organization.

The authors discuss how these rules are in the basis of the TPS, and how they create an environment with high delegation level that enables decentralized and continuous change without creating chaos.

FUJIMOTOS'S 3 CAPABILITIES

Fujimoto (1999) analyzes the TPS from an evolutionary point of view and identify three levels of capabilities that explain its sustained high performance and continuous improvement:

- **Routinized manufacturing capability** – related to the standard and accurate way to perform activities in all company's processes;
- **Routinized learning capability** – routines for problem identification, problem solving and solution retention;
- **Evolutionary learning capability**. – intentional and opportunistic learning capability of handling system changes in building the above routine capabilities

The author reinterprets manufacturing activities as an information system, and summarizes the production capability of the most effective Japanese automakers as "dense and accurate information transmission between flexible (information-redundant) productive resources" (Fujimoto, 1999, p.108). The "dense" aspect is related to productivity, efficiency, and waste elimination. The importance of a regular pace of information transfer is also emphasized. Quality is interpreted as accuracy of information transmission.

DEPLOYING PRINCIPLES IN CORE ELEMENTS

The three approaches briefly referred previously give us a better understanding of the lean philosophy and its core concepts. To apply these concepts in different environments (as other industries, including construction) it is interesting to deploy these ideas or principles in detailed concepts, but not reaching the operational field, provided by techniques.

Table 2 presents a proposal of this deployment in core elements, showing related techniques in the right column. The conceptual part of this Table (all columns but the techniques column) is presented as a tree, expanding from objectives and Womack and Jone's five values to more detailed concepts, named "core elements", presented in two levels of detailing (columns three and four).

Spear and Bowen's and Fujimoto's approaches, although represent different emphasis and perspectives, are considered in Table 2 related to Womack and Jone's five principles. Spear and Bowen's rules: work highly specified, pathway and connections and Fujimoto's routinized work capability can be related to Womack and Jone's Flow and Pull values. Spear and Bowen's improvement rule and Fujimoto's routinized and evolutionary learning capabilities can be related to Womack and Jone's Perfection principle.

This tree representation is simplified. Some "core elements" are in truth related to several principles, as well as many techniques are related to different core elements. The aspects depicted in Table 2 are more conceptual to the left (philosophy) and more operational, to the right (techniques). The system level, not depicted in this Table, would combine techniques, according to the philosophy. The core elements, as the most detailed conceptual level, are in the border between philosophy and techniques, providing a valuable basis for lean systems design, mainly in different environments, where some techniques, developed in the original environment, can be inapplicable.

We argue that the discussion of Lean Thinking application to environments different than manufacturing is facilitated if focused on the core elements presented in Table 2. For example, the discussion of the technique "fast set up" can be difficulty in industries as construction and services, but the related core element "flexibility" can be discussed and deeply understood considering the specific characteristics of the desired environment.

The core elements presented in Table 2 depict, in an intermediate level of detailing, what one should find in a Lean Enterprise, aiming the objectives and principles. Discussing these core elements can help a company to design its systems and selecting, adapting or developing appropriate techniques.

Table 2 – Lean core elements

Objectives	*Principles*	*Core elements*		*Examples of related techniques*
Permanently improve company's competitiveness by: - eliminating waste - consistently attending client's requirements in variety, quality, quantity, time, price	VALUE	Enhanced product / service package value	Solution that enhances value for the client	Identification of what is value for the client, services aggregation, business re-structuring
			Product variety	Modular design, interchangeability, fast set-up, planned variety compatible with production system
		Time based competition	Production lead time (order to delivery)	Small batches, product family factory lay-out, JIT
			Product development lead time	Black box system, heavyweight manager, set based design, concurrent engineering
	VALUE STREAM	High value adding in the extended enterprise	Value stream redesign eliminating waste	Mapping, combining activities, eliminating non-adding value activities, supporting and promoting suppliers lean implementation
			Suppliers involvement in production and product development systems	Partnership, supplier training, black box system, JiIt supply
	FLOW	Dense, regular, accurate and reliable flow	Dense flow , with hight adding value time, clear pathways and communication	Mapping, work cell, one piece flow, multifunctional worker, autonomation, product lay-out, design for manufacturing
			Regular flow - paced by client / next process demand	Takt time, kanban, one piece flow
			Accurate and reliable flow	TQC, statistical process control, poka-yoke, jidoka, Total Productive Maintenance (TPM)
		Standard work	Work standardization	Work instructions, work content, cycle time and standard inventory definition
			Transparency	Visual management, 5S
			Low level decision	Delegation, training
	PULL	JIT production and delivery	Pull versus push system	Kanban, takt time
			No overproduction, WIP (Work In Process) reduction	Kanban, standard inventory, FIFO:firt-in-first-out, small batches, one piece flow
			Demand smoothing : harmonizing market variations and production flexibility	Anticipation (Master plan), Peaks negotiation (Dealers system)
			Reflecting product variation in short periods of production	Heijunka, fast set-up, small batches
		Flexible resources	Information flexibility	Flexible information systems
			Equipment flexibility	Fast set-up, low cost automation, redundant equipment
			Workers flexibility	Multi-skill training, work cell
	PERFECTION	Learning	Fast problem detection	No buffer, no stock, kanban, small batches, one piece flow, first-in-first-out (FIFO), visual management, 5S, decision in operator level
			Fast problem solving in lower level and solution retention	Empowerment, teamwork, Quality Control Circles (QCC), 5 Whys, quality tools, kaizen
			Evolutionary learning	Kaikaku (dramatic changes), benchmarking
		Common focus	Leadership and strategy	Strategic planning, Policy deployment, Hoshin management, managers in workplace
			Structure	Teamwork, hierarchy levels reduction, cross functional structure
			Client and production focus diffusion	Training, day by day coaching, leadership example
			Human respect	Laying off as the last resort, Job system, work meaning enrichment, participation, empowerment, recognition, ergonomy, safety
			Total employee involvement	Suggestion system, QCC, kayzen, job system, training system
			Total system diffusion	Techniques standardization, simplicity in communication, system and techniques application in all processes and in whole company

CONSTRUCTION FLOWS

Lean Thinking states its concepts application in the whole company, considering the main flows in an enterprise (Womack, 1999):

- From order to cash;
- From concept to launch;
- From raw materials to customer;

Recently, these flows were extended, including "in use through life cycle to recycling" (Womack, 2000). A schematic representation of these flows is presented in Figure 1[5].

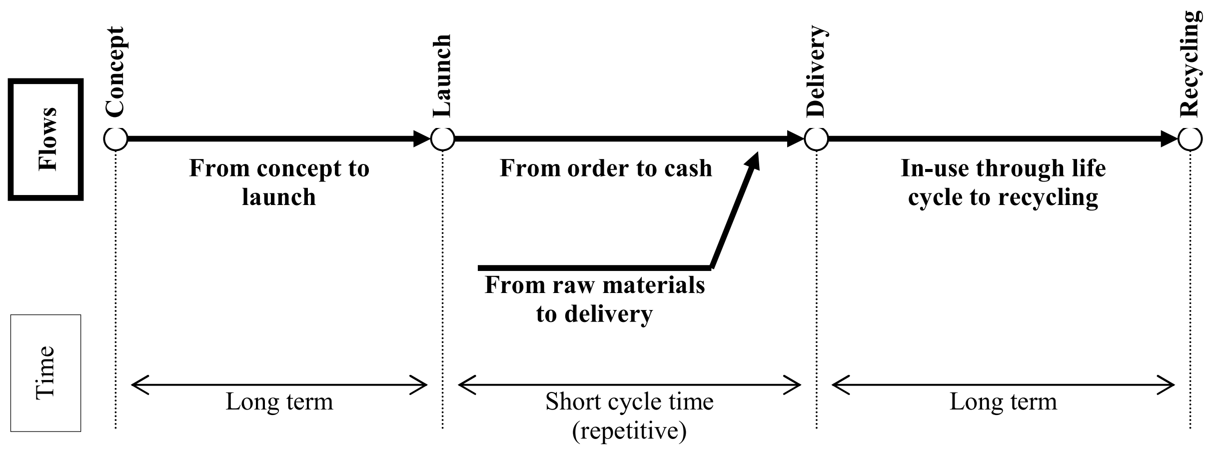

Figure 1 - Flows in manufacturing

In manufacturing, the three flows before delivery can be well characterized inside one plant, inside one corporation, or within the total value chain. In Construction, each flow meaning must be interpreted, for each value stream participant and for the whole project, as well – Picchi (2000). We present in Figure 2 an interpretation of these flows, considering the construction project level, thus involving all participants.

We named "Business Flow" the flow led by the owner, involving since the construction needs identification, project general planning, designing and construction contracting and monitoring, and construction delivery for use for the final client

The design flow is generally led by the Architect, and involves the owner (needs identification and project briefing) and all designers as main participants. The general contractor leads the job site flow, frequently using a high level of sub-contracting. The supply flow involves several products (materials and components), and is similar to the supply chain in any other sector. The separation between design flow and job site flow is not so clear as in

[5] Womack (2000) defines the flows as: design (concept to customers), build (order to delivery, combining the previous "order to cash" and "raw materials to delivery" and sustain (in-use trough life cycle to recycling). In Figure 1 we maintained the separation of the flows "order to cash" and "raw materials to delivery".

manufacturing. Even in the development market, where there is a "product launch", some design activities, as shop drawings and detailing, overlaps the production, on job site.

Figure 2 shows the relationships among these flows, also representing the use and maintenance flow, which starts after construction delivery (equivalent to the "sustain flow" in manufacturing). This flow comprehends: use, operation and maintenance, as well as repair, refurbishing, remodeling and demolition. The companies involved in the use and maintenance flow mostly are different from those involved in the flows before delivery.

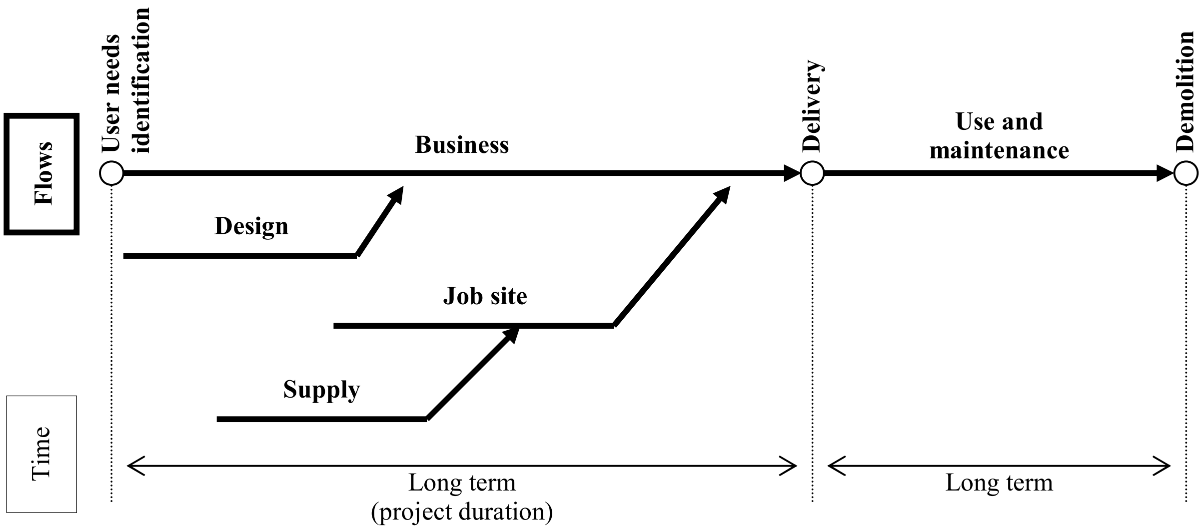

Figure 2 –Flows in construction

A brief comparison between Fugures 1 and 2 shows us one difference between construction and manufacturing: the long term project duration, versus the repetitive short cycle time production.

OPPORTUNITIES, IN A SYSTEM VIEW

We show in Table 3 some examples of opportunities of applications for each cell of the proposed framework, just as a schematic view of the enormous opportunities for Lean Thinking application in construction[6]. Several other opportunities and works done so far can be identified, as discussed by Picchi (2001).

Any isolated application has no meaning, from the system point of view. The strength of lean enterprise system is in the complex relationships among all these possible actions. Table 3 shows us in the lines the combination of different techniques for each core element trough all flows. In the columns we can see the necessary integration of all core element

[6] For the use and maintenance flow the opportunities were presented in a simplified way, grouping core elements, reflecting the few discussion about lean application to this flow.

implementation, for each flow. Every application, if plotted in this framework, can be better understood, from the lean philosophy point of view.

Some opportunities were identified as a vision of suitable applications with expected results for the construction sector, but with no practical use so far. Other opportunities have already been used, showing its applicability to the construction sector. The detailed discussion done by Picchi (2001) shows that the efforts so far are concentrated in the job site flow, followed by design and supply flows, and mainly in the core elements related to flow and pull.

The main lacks are in core elements related to value, value chain, and perfection, and in the business and use and maintenance flows, important subjects for future studies. The business flow coordinates the whole project, and can enable or hinder lean application in other flows. The use and maintenance flow, including all activities other than new construction, is reaching one half of construction activities, in advanced industrial countries (Bon and Crosthwaite, 2000, p.18).

Table 3 – Examples of opportunities for Lean Thinking application in the construction sector

Princ	*Lean Core Elements*	*Construction Flows*				
		Business Flow	***Design Flow***	***Job Site Flow***	***Supply Flow***	***Use and Maintenance Flow***
Value	**Enhanced product / service package value**	- integrating real estate, design, construction, financial services - customizing product by late detailing and specification	- identifying and attending customer needs using QFD and other techniques - enhancing product features, such as flexibility, upgradability, etc	- combining product/process technologies that enhances features desired by the client (ex.: easy assembly process enhancing interchangeability and maintainability)	- developing components that enhances constructability as well as value to the final client	- integrating business flow and use/maintenance flow - integrating maintenance and and operation processes
	Time based competition	- changing business strategies offering products with short construction times - overlapping activities	- reducing design time using concurrent engineering	- reducing construction time by waiting time reduction	- reducing supply time using JIT	
VS	**High value adding in the extended enterprise**	- redesigning relationships among project agents - reviewing contracting polices	- mapping and eliminating rework and waiting among designers - early involving suppliers and sub-contractors in project design process	- redesigning sub-contractor structure, organizing work and teams by modules	- mapping and eliminating inventory and other wastes within the whole supply chain	
Flow	**Dense, regular, accurate and reliable flow**	- adopting an explicit activities sequence with regular pace - adopting quality system within the whole project	- adopting set based concurrent engineering - exchanging information in small packages - quality checking after each design process	- mapping and eliminating non-value adding activities, such as transport, waiting, etc. - choosing right technology – equipment size and processes that maximize the flow - adopting quality control and poka-yoke (mistake-proof devices and procedures) - assuring equipment reliability using TPM	- adopting takt concept (pacing all activities by customer actual demand) within the whole supply chain - reducing lead time in the administrative purchase process, using kanban, e-commerce, etc.	- standardizing work in use and maintenance proceses - mapping and optimizing use and maintenance flows - training multi-task workers - developing sub-contractors and suppliers to work in a pulled system
	Standard work	- standardizing procedures among project agents - using extranets for information exchange	- standardizing design process (information sources, sequencing, presentation, cycle times, etc)	- standardizing job site processes (work description, necessary tools, cycle time, etc.) - adopting visual control for job site tasks (progress, problems, quality, etc.)	- standardizing supply kits for construction modules - standardizing supply cycles	
Pull	**JIT production and delivery**	- eliminating information waiting - delivering construction in small areas as necessary	- pulling design process by target events - delivering information as necesary	- eliminating pushed planning adopting pulled systems between different crews and between crews suppliers (kamban, last planner, etc.) - reducing work in process using small modules delivery	- adopting JIT production and delivery within the whole supply chain - delivering supply kits for construction modules as necessary	
	Flexible resources	- planning flexibility in all involved agents	-- partnerships between design offices	- using flexible equipment - training multi-skilled workers	- enhancing supply chain flexibility (right equipment, fast set-ups, small batches, etc)	
Perf	**Learning**	- consolidating lessons learned at the end of every project - reviewing the business system at the beginning of projects	- adopting systematic design learning from job site and use/maintenance	- involving sub-contractors in problem-solving teams	- eliminating buffers for fast problem detection and solving	- collecting data for learning from use and maintenance - focusing on use and

ec.	**Common focus**	- implementing lean systems in all companies involved in the project	- enhancing client and job site focus	- creating means for all workers participation in processes improvement, including sub-contractors crews	- developing lean suppliers	maintenance since design, involving all participants

CONCLUSIONS

Lean thinking is a complex concept and the understanding of the integrity philosophy-system-techniques is fundamental for successful implementations. Using the proposed framework, crossing core elements and construction flows, is a useful approach for identifying opportunities for applications, providing the necessary system view.

As discussed previously, isolated techniques implementations have very limited results. On the other hand, the implementation of all opportunities depicted in Table 3 needs priorities, action plans, cooperation among project participants, etc. This brings us to the major issue of implementation strategies, a great concern of companies from all industries interested in the lean transformation. The complete implementation of a lean system in a company takes at least five years (Womack and Jones, 1996), and keeping in mind the complete framework since the first steps and understanding the meaning of intermediate stages in the complete system is certainly a critical success factor.

Considering the sector complexity and its characteristics, we can say that important steps have been done, even if compared with other sectors, more similar to automotive industry. Considering the wastes in the construction chain and the many opportunities shown, we conclude that a lot is still left, until we have a real case of application covering simultaneously most core elements and construction flows. Due to construction complexity and fragmentation, this is a goal that can be pursued only by a network of researchers, practitioners, companies and institutions.

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