

The Practical Relationships between Lean Construction Tools and Sustainable Development: A literature review

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Abstract

The construction industry is considered among the largest consumers of natural resources (non-renewable materials, fossil fuels, water...). It is also an important source of generation of solid waste and greenhouse gas emissions. In addition to its negative impacts on the environment, most construction projects are characterized by the non-respect of the triptych (Cost, Time, Quality) and a high accident rate compared to other sectors. Lean construction (LC) is a new production philosophy which has the potential of bringing innovative improvements in the construction sector. It is a systemic approach to meeting customer expectations by maximizing added value and reducing all forms of waste. Based on international standards (AFNOR, GRI, UNEP, ISO 26000...) and recent researches published in the most reliable databases, this study aims at exploring the concept of sustainable development in the context of the construction industry and examines how the LC tools (Prefabrication, Value Stream Mapping, Poka-Yoke, visual Management, and 5S) can have an impact on the three dimensions of sustainable development (environment, economy, society). This work brings a new reflection by constructing an interaction matrix between the Lean Construction tools and sustainable development.

Keywords: Lean Construction, Sustainable development, Interaction matrix

1. Introduction

The sector of construction represents an integral part contributing tangibly to the economic growth of developing countries. At the national level, the sector of construction is considered amongst the most dynamic and the most promising of the Moroccan economy, it contributed by 6.3% of total value added created in 2014 with an increase of 4% compared to 2013 [1]. It employs nearly a million people (9,3% of the active population) [2].

On the other hand, even if the construction industry participates in strengthening the national economy and reducing the unemployment rate, this sector also has a huge impact on the environment compared with other industries, and it is considered within the most polluting sectors [3, 4].

The construction industry is a very large consumer of non-renewable resources. Similarly to its damaging effects, it is also an important source of natural resources waste (non-renewable materials, water...), solid waste generation and greenhouse gas emissions.

In Morocco, almost 9 million tons of solid waste are dumped every year in nature [5]. Besides that, the Moroccan construction industry is considered as the largest consumer of energy; it accounts 36% of final energy consumption and 32% for the manufacturing sector [6]. Moreover, it is considered among the sectors of activities having a great impact on air pollution and the deterioration of the ozone

layer; it is a source of 45 million ton of CO₂ (in 20 years, CO₂ emissions have increased by more than 200 %) [7].

In addition to its negative impacts on the environment, most construction projects are characterized by high variability and high accident rate compared to other sectors [8]. According to the last studies carried out by Lean Construction Institute (LCI) [9], the sector of construction is characterized by a ratio production/waste higher than that of the manufacturing sector as could be seen in Fig. 1.

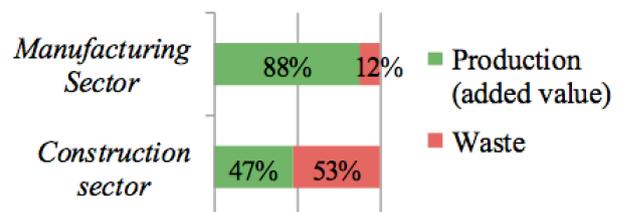


Fig. 1. Comparison of Production/waste ratios between manufacturing sector and construction sector

It has become crucial to seek creative and innovative solutions that ensure better and more optimized modes of management. Because of its great potential in achieving customer expectations in terms of increasing the value and reducing all forms of waste, the Lean Construction philosophy is considered an alternative approach which can bring revolutionary changes to the construction industry.

The LC is a concept that derives from the manufacturing industry, adopted in the industry of construction with its objectives to minimize waste and maximize the value added

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in construction projects. LC is a proven method for the management and optimization of the construction process, hence the requirements of customers can be reached using good resources and as well its ability to provide the best quality from the first time.

Various lean tools for achieving sustainable development have been discussed by several authors. However, in the literature, there are only a very few studies that have explored various issues of sustainability by means of lean construction initiatives and established the benefits that can be derived by applying the lean tools. The purpose of this study is to analyze the concept of sustainability in the context of the construction industry based on a literature review of scientific contributions published in reliable journals.

This work brings a new reflection focusing on the relationship between lean construction tools and the three challenges of sustainable development (environment, economy, society).

2. The concept of sustainable development

2.1 Sustainable construction

Sustainable construction is mainly defined by the industry that ensures the conservation of natural resources throughout the life cycle of the building (energy, water, non-renewable materials), optimizing the consumption of raw materials in purpose to reduce the deterioration of the environment and to ensure social and economic comfort [10].

A sustainable and ecological construction project must necessarily take into account the objectives of sustainable development at every stage of decisions: design, construction, use, and demolition. In addition to these earnings to the level of socioeconomic development and the protection of the environment sustainable construction practices ensure other intangible benefits such as strengthening the company's name in the market, the resistance to global competition, improving the quality of infrastructure and creation of working conditions guaranteeing motivation and employee satisfaction [11].

2.2 The main factors of sustainable development

There are several definitions of sustainable development in the literature, especially that sustainable development is a broad concept that has been adopted and interpreted in many contexts. The most popular definition of sustainable development is that given in the Brundtland report [12]:

“Development that meets the needs of the present without compromising that ability of future generations to meet their own needs”

In order to assess the impact and contribution of the lean construction philosophy in sustainable development, we have clarified the key factors of the three dimensions (economy, environment, and society) based on international standards (AFNOR, GRI, UNEP, ISO 26000...) and on recent research published in the most reliable international journals. The most common factors of sustainable development are shown in Tab. 1.

Economy	Innovation/R&D ⁴	[3, 4, 14, 15]
	Cost saving ¹	[3, 4, 11, 14, 15, 16]
	Increase added value ⁵	[3, 11, 13, 14]
	Time reduction ¹	[3, 11, 14, 15]
	Partnering ³	[3, 13]
	Competitiveness ²	[6, 11]
	Waste Reduction ¹	[3, 11, 13, 14, 17]
	Measure customer satisfaction ⁵	[11,15, 16]
	Responsiveness ³	[15, 18]
	Flexibility ²	[4, 14, 15]
Increase workers productivity ¹	[11, 15]	
Environment	Material and resources ⁶	[3, 4, 16, 18, 19, 20]
	Energy efficiency ⁶	[3, 4, 16, 18, 19, 20]
	Emission of greenhouse gases ⁸	[3, 4, 16, 18, 19, 20]
	Water efficiency ⁶	[3, 4, 19, 18, 20]
	Solid wastes ⁹	[3, 16, 20]
	Resource depletion ⁶	[16, 18, 20]
	Pollution Prevention ⁷	[4, 16]
	Production of toxic products ⁷	[3, 4, 16, 21]
	Solid waste treatment ⁹	[19, 22]
Use of land ⁶	[3, 4, 18]	
Society	Working conditions ¹⁰	[3, 4, 16]
	Health and safety (e.g. employees injuries, fatalities) ¹⁰	[3, 11, 16]
	Labor/Management Relations ¹⁰	[3, 11, 16]
	Employment contribution ¹¹	[3, 4, 16]
	Education/training ¹¹	[3, 4, 16]
	human resource development ¹¹	[3, 16]
Employment ¹²	[3, 4, 12, 16, 23]	

The analysis of the data in Tab. 1 has allowed us to identify twelve main factors, as shown in Fig. 2, spread over the three dimensions of sustainable development (Economy, Environment, and Society). These main factors encompass the thirty factors that were found in the literature and international standards. They are identified in Tab. 1 by the exhibitors ranging from 1 to 12 depending on the correspond issue. These main factors will be used in the development of a matrix of interaction between LC tools and the three dimensions of sustainable development.

3.1 Origin

The study carried out by Pappas [24] in 1990 noted that only 11.4% of the time on construction site created added-value. Other Swedish studies in their turn, have observed that the operations which create added value represent only 30% of time spent on a construction site [25, 26].

LC is a new philosophy of production, representing the adaptation of the concept Lean manufacturing with the peculiarities of the construction industry. Due to its great potential in fulfilling objectives in term of increasing the added value and productivity LC has gradually interested stakeholders of the construction industry.

The discussions relative with the concept of LC began in 1992 when Koskela thought of introducing Lean philosophy

Table 1. The factors of sustainable development

Dimensions	factors	References
	Productivity/profitability ¹	[3, 4, 13, 14, 15]
	Quality ¹	[3, 4, 11, 15, 16]

in the management of construction projects [27]. While taking as a starting point the model of Toyota Production System (TPS), Koskela invented theory TFV (Transformation, Flow, Value) [13] as is shown in Tab. 2.

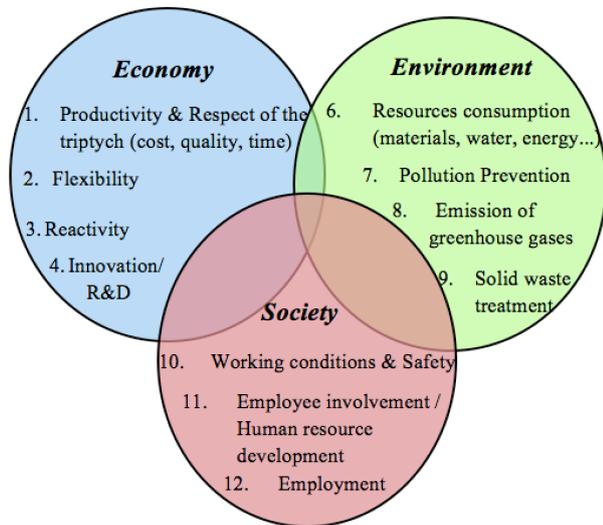


Fig. 2. The main factors of sustainable development

3. Lean Construction

Table 2. TFV (Transformation-Flow-Value) theory of lean construction

	Transformation	Flow	Value
Concept of production	A transformation of inputs into outputs	A flow of materials, composed of transformation processes, inspection processes, movements and waiting	A process where the value for the customer is created by the realization of its requirements
The main Principle	To have an efficient production	Elimination of waste (non-value-added activities)	Elimination of the losses of value (value obtained by report to the best possible value)
Practical contribution	Take care of what must be done	Take care that what is non-necessary should be reduced to the maximum	Take care to meet customer's requirements in the best possible way

3.2 Definitions of Lean Construction

LC philosophy doesn't have a single definition in the scientific references, it's still evolving as the academic research, in particular doctoral research, feed this concept.

The most common definitions used in the literature are cited in Tab. 3.

Table 3. Definitions of Lean Construction

Researchers	Year	Definitions
Dupin [28]	2014	LC aims to create value for the customer by the elimination of the waste, supported by collaborative project management tools, as part of a systematic and rigorous approach of continuous improvement.
Howell and Ballard [29]	1998	The LC is designed to better meet the needs of customers by using fewer resources.
Koskela [27]	1992	A way to design the production system to minimize waste of materials, time and efforts, in order to generate the maximum possible value of the end product.

Overall, it can be concluded that LC is a new way to organize the management of construction projects in such a way as to reduce the sources of waste and generate the maximum value for the customer using the least resources.

3.3 Waste in the construction sector

The seven forms of wastes in the construction industry are: waiting, motion, over processing, overproduction, transportation, inventory and defects [30]. Many scientist and professionals consider that the negligence of the seven form of waste by stakeholders during the construction phase is the main cause of the problems of cost overruns and delays in the construction industry [11, 28].

LC considers the construction process as a process flow, combined with transformation activities, contrary to the method of traditional construction which focuses only on the improvement of the steps which create the added value. According to Dupin [28], value-added activities (Direct work) don't exceed in most of the time 32% of time spent on site, as shown in Fig. 3.

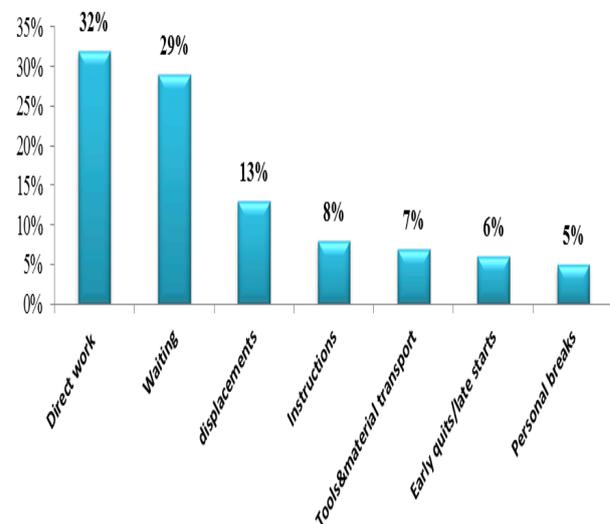


Fig. 3. Proportions of activities generating waste in the construction industry

3.3 Lean Construction tools

Many researchers have confirmed the usefulness of the LC concept for projects of construction [4, 15, 31]. The main advantage that companies could reduce the costs invested in construction projects by using fewer resources and reducing waste on production sites. In addition, by having a proper project planning, it would shorten the duration of the construction project. Based on an analysis of the scientific research conducted in several countries, we found that the most appropriate LC for the construction industry are as follows : Last Planner System (LPS), Visual management (VM), 5S, Value Stream Mapping (VSM), Building Information Modeling (BIM), Prefabrication, Analysis of roots causes (5 Why, the Ishikawa diagram , PDCA...), Just In Time, Poka-Yoke, as shown in Tab. 4.

Table 4. Lean Construction tools most used in the construction industry

Researches	Last planner system	VM	5S	VSM	BIM	Prefabrication	Root cause analysis	Just In Time	Poka-Yoke
[32]			x	x	x		x		
[9]	x	x	x	x	x		x	x	
[28]	x	x	x	x	x		x	x	x
[33]				x		x			
[34]						x		x	
[35]	x	x					x	x	x
[30]	x	x	x				x	x	x
[31]	x	x				x	x	x	x
[11]	x		x	x	x				x

In this study, we will focus on the direct interaction between five LC tools (Prefabrication, Value Stream Mapping (VSM), Poka-Yoke, Visual Management (MV), and 5 S) and twelve mains factors of sustainable development.

4. The contribution of LC tools in sustainable development

The promotion of the economy without taking into account other dimensions of sustainable development will certainly generate adverse effects on the environment and social comfort (health, safety, employment...). As well, the availability of natural resources on our planet (fossil fuels, water, steel, wood...) continues to decrease.

Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Indeed, Sustainable construction is the response of the construction industry to meet the challenge of sustainable development [31, 36].

In the literature, there is very little research which takes into account the contribution of LC philosophy on the three aspects of sustainable development (economy, environment, society).

Most searches are focused more on the economic issues of the construction industry and optimization of the triptych (quality, cost, time). Various lean tools and techniques for enabling sustainability have been discussed by several authors. Some studies have explored various issues of sustainability by means of lean initiatives and established the benefits that can be derived by applying the lean principles/tools.

This work follows the new paradigm of sustainable management of the construction projects as illustrated in Fig.4.

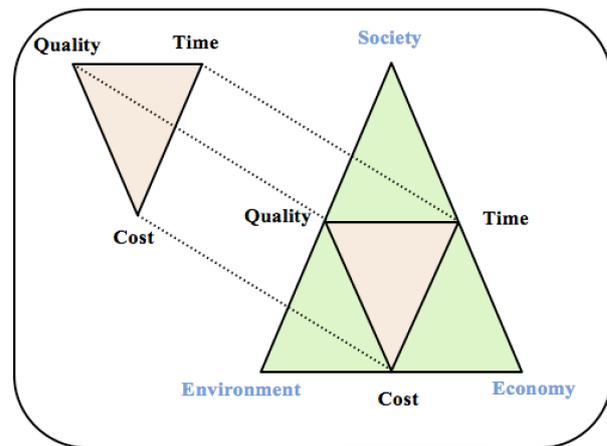


Fig. 4. The new paradigm of sustainable management of the construction projects

4.1 Prefabrication

The existing literature has identified some modern methods as a means of reducing the production of waste in the construction industry.

Prefabrication is one of the new techniques to ensure that the components are manufactured and assembled off-site. Several practical cases have shown the efficacy of this technique in reducing waste. For example, the two studies [37, 38] show that the tendency of the waste in the construction projects can be reduced to 52% and 84.7% respectively, compared to the traditional construction.

The contribution of prefabrication in promoting the sustainability of construction projects, according to the three facets of sustainable development, is illustrated in Tab. 5.

Table 5. The contribution of prefabrication in sustainable development

Dimensions	Practical contributions	Ref
Environment	Reduces the impact on the environment due to the transfer of a large part of the construction process to a specialized factory in prefabrication.	[34]
	All these facts can be translated into many benefits such as less : storage of raw material, noise, air pollution (dust), waste and energy consumption	
	Prefabricated components are more likely to be easily	[14]

	disassembled in the demolition phase which facilitates their treatments (reuse, recycling, etc) and reduces solid waste	
	Selection of non-toxic, reusable and recyclable materials during the design phase.	[39]
Economy	Reducing waste on site reduces construction cost, allows to respect the deadline and to increase the quality of the project.	[38]
	The development of new materials	[14]
	Flexibility and adaptability	[14]
Society	Provides safer working conditions (e.g., Reducing dangerous tasks such as welding, cutting that may threaten the worker's safety)	[37]
	The strengthening of a prefabrication industry will certainly contribute to the creation of employment opportunities and the development of the technical skills of the staff.	[34]

Despite the great advantages of prefabrication, this technique shows some disadvantages. At the economic and social level, less labor is requested for projects based on prefabrication, thus fewer employment opportunities especially for staff working on construction sites.

At the environmental level, this process can consume more energy for the transport of prefabricated products and emit more air pollution [14, 39]. A contractor applying prefabrication technique in its project should absolutely identify the best method of supply by using a holistic approach during the life cycle of the project.

4.2 Value Stream Mapping

Value Stream Mapping (VSM) allows to graphically representing the set of steps constituting the construction process in such a way that the user of this technique can easily understand the circulation of the flow (materials, information). According to [14], in contrast to traditional methods the VSM helps to identify activities adding value for the customer and those without added value (non-value added activity).

By analyzing the consumption of certain materials (brick, wood, concrete) in the walls construction process Rosenbaum [40] has verified the usefulness of the VSM in promoting the three dimensions of sustainable development. The contribution of the VSM in the promotion of the sustainability of construction projects is shown in Tab. 6.

Table 6. The contribution of Value Stream Mapping in sustainable development

Dimensions	Practical contributions	Ref
Environment	Allows to measure the consumption of any type of resource (water, energy, materials...), and quantify the sources of pollution (waste, emissions released into the atmosphere)	[40]
Economy	The detection of the sources of waste allows to reduce the financial burden of the project and to shorten the time of completion of the project.	[14]
Society	Facilitate workflow (load balancing, reducing the complexity of the process, minimizing unnecessary travel ...)	[28]

4.3 Poka-Yoke

Poka-Yoke, a Japanese word, is simply a mechatronics device that operates as a mistake-proofing to automatically prevent defects from flowing through the process (Fig. 5).

Although this technique was used for the first time by Toyota to improve the quality of its products, the ideas behind this concept could be used to improve the productivity, quality, and safety of staff on construction sites. A typical example, such as controlling the addition of water during the production of mortar, as could be seen in Fig. 6.

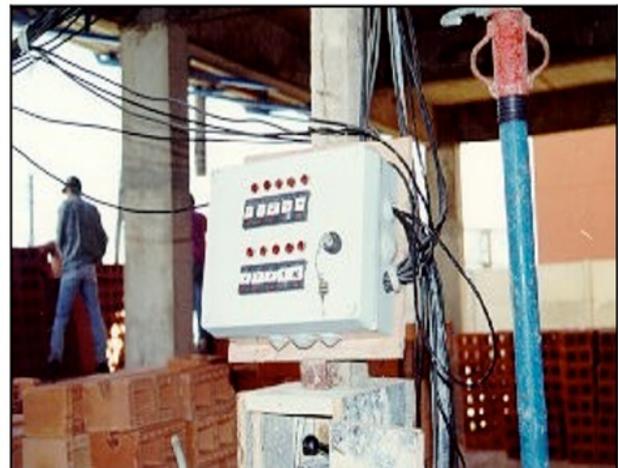


Fig. 5. Using the Poka-Yoke devices in the construction process



Fig. 6. Using Poka-Yoke devices during mortar production process

Generally, this activity is carried out manually, without any strict control of water consumption which affects the quality of produced mortar. According to Dos Santos [41], the cost lost to solve the problems of non-compliance, errors and changes in construction projects are approaching 10% of the total project cost. The contribution of Poke-Yoke in the promotion of the sustainability of construction projects is shown in Tab. 7.

Table 7. The contribution of Poka-Yoke in sustainable development

Dimensions	Practical contributions	Ref
Environment	Reduces the consumption of resources (water, materials, energy)	[41]
	Control emissions of pollutants (greenhouse gas, solid waste)	
Economy	A positive impact on the triptych (quality, cost, time), therefore companies can better respond to customer requirements.	[41]
Society	The Poka-Yoke devices could also protect workers against excessive heat, noise, and some other dangers. In some cases, these devices are used as alarms to prevent labor from approaching or cross (e.g. Fall of objects, concrete in waiting for drying...)	[8]

Besides these advantages, the implementation of this technique in construction projects will definitely contribute to the reinforcement of a specialized industry in developing Poka-Yoke devices, so more employment opportunities will be created. Training on this new technology will be necessary to improve the skills of the workforce working on construction and familiarize them with these new devices which lead to ongoing staff development and continuous improvement of the process of construction.

4.4 Visual Management and 5S

5S is the acronym for Sort (Seiri), Simplify (Seiton), Sweep (Seiso), Standardize (Seiketsu), and Self-discipline (Shitsuke). It helps to make a suitable site for the flow of value-added activities by holding everything in its place. The 5S process is considered among the first steps that an organization should take in implementing the LC philosophy. Visual management makes the construction process transparent, simple and safe for all stakeholders on site through digital billboards, signs of security and graphical dashboards. These tools allow to facilitate enormously the construction process and to improve the performance of the communication between the coordinators of the project. The comparison between Fig. 7 and Fig. 8 shows the usefulness of the visual management for the organization and transparency of construction projects [42].

The contribution of the visual management and 5S in the promotion of sustainability of construction projects according to the three facets of sustainable development is shown in Tab. 8.

Table 8. The contribution of Visual Management and 5S in sustainable development

Dimensions	Practical contributions	Ref
Environment	Reduce the waste of materials in stock	

	Make easier the sorting of the solid waste	[43]
Economy	Reduce the variability of the construction process	
	Strengthens the company position amongst competitors and gives confidence to the customer	[44]
Society	A well-organized workplace allows to security and productivity among employees that the main cause of accidents on construction site is due to disorder noticed in site of construction	[8]



Fig. 7. The traditional method of organizing construction sites



Fig. 8. Organization of construction sites based on visual Management and 5S

4.4 Synthesis & Discussion

Sustainable construction is a new concept that requires checking the objectives of sustainable development at all stages of decision making (design, construction, use, and demolition).

In this study, we were based on the analysis of concrete results that have been observed during the execution of several projects of sustainable construction in many countries (United State, United Kingdom, China ...), and especially those adopting a strategy of resources optimization according to the LC philosophy.

The objective of this study is to examine the practical relationship that may exist between the LC tools (prefabrication, Value Stream Mapping (VSM), Poka-yoke, visual management (VM), and 5S) and the sustainable development issues, which allows to have a feedback on the

level of impacts, either positive or negative, related to the application of the techniques of LC in sustainable construction projects.

Tab. 9 represents an Interaction matrix that allows identifying the impacts of the different LC tools studied in this work. These impacts are divided into three categories: environmental, economic, and social.

Table 9. The Practical Relationships between Lean Construction Tools and Sustainable Development

	Prefabrication	VSM	Poka Yoke	5S and visual Management
Environment				
Resources consumption (materials, water, energy...)	+	+	+	+
Pollution Prevention	+	+	+	+
Emission of greenhouse gases	±	+	+	
Solid waste treatment	+	+		+
Economy				
Productivity & Respect of the triptych (cost, quality, time)	+	+	+	+
Flexibility	+			
Reactivity	+			
Innovation / R&D	+	+		
Customer satisfaction	+	+	+	+
Society				
Working conditions & Safety	+	+	+	+
Employee involvement / Human resource development	+		+	
Employment	±		+	

Tab. 9 shows the practical relationships between the studied LC tools and the three dimensions of sustainable development (environment, economy, society). Generally, we can notice that most of these tools generate positive impacts on the majority of the issues of sustainable development, except for the prefabrication which could have

both positive and negative. At the environmental level, prefabrication brings great benefits for sustainable construction by the use of non-toxic, recyclable, and easily removable materials during the phase of the demolition of building structures. However, this technique requires more energy resources for transportation of prefabricated products, therefore more greenhouse gases will be emitted into the atmosphere. At the social level, the strengthening of a structured prefabrication industry will certainly contribute to the creation of employment opportunities, the development of technical skills of staff and the improvement of working conditions as a result of the transfer of a large part of the process of construction to plants specialized in prefabrication. Even so, there are some problems related to the reduction of certain manual workstations that characterize the traditional construction system, so fewer employment opportunities will be created especially for the staff working on construction sites.

5. Conclusion

The construction industry represents an integral part that contributes tangibly to the strengthening of the national economy and the reduction of unemployment. Nevertheless, this sector is considered among the main sources of greenhouse gas emissions and solid waste generation. Thus, it is one of the largest consumers of natural resources. Lean Construction is a way to design production systems in order to generate the maximum value for the customer by reducing the waste of materials, time, and efforts. It is a new concept which can bring revolutionary changes and great benefits to the construction industry. In this study, the practical relationships between lean construction tools and sustainable development have been extensively explored. It has been established that the LC tools (Prefabrication, Value Stream Mapping, Poka-Yoke, visual Management & 5S) have a direct impact in promoting the main factors of sustainable development. Indeed, we have demonstrated that Lean Construction not only contributes to creating the economic value to the construction process but can also contribute to promoting the environmental and social issues. This philosophy represents a strong conceptual basis to achieve the objectives of sustainability. More empirical studies should be conducted in the future to quantify the influence of LC practices on the sustainable construction.

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