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# The potential effectiveness of lean construction principles in reducing construction process waste: an input-output model

**M.S. Bajjou* and A. Chafi**

Faculty of Sciences and Techniques
University of Sidi Mohammed Ben Abdellah
B.P. 2202 - Route d'Imouzzer, Fez, Morocco
Department of industrial engineering
Industrial Techniques Laboratory
Phone: +212602675723
* E-mail: mohamedsaad.bajjou@usmba.ac.ma

## ABSTRACT

With the spread of a culture of waste reduction in the construction industry, the traditional management system has become insufficient, so it has become crucial to implement more innovative techniques to improve the performance of this sector. In response to this need, Lean Construction (LC), which is the global reference of a production system with the minimum of waste generation, has attracted several construction companies all over the world. However, previous studies indicate that are several implementation scenarios that differ from one company to another according to their own understanding of the Lean Construction concept. In this paper, the authors attempt to fill this gap by proposing an original input-output model that aims at clarifying the main conceptual basis of Lean Construction philosophy, as well as establishing interactions between the main principles of this concept and all sources of wastes that exist in the construction industry. The proposed model shows nine main principles: customer focus, supply, continuous improvement, waste elimination, people involvement, planning and scheduling, quality, standardization and transparency. In addition, the practical relationships between those principles and nine sources of waste (transportation, motion, inventory, waiting, overproduction, defects, over-processing, unused employee creativity, and work Accidents) have been analysed.

**Keywords:** Lean Construction principles; sources of waste; waste reduction; practical relationships; input-output model.

## INTRODUCTION

The sector of construction, according to several studies, is highly characterized by many problems such as low productivity, non-added-value generation, time and cost overrun, poor safety conditions, and a high variability of its construction process [1,2]. Indeed, several solutions had been proposed to overcome the weaknesses of the construction industry like the use of new computer technologies as Building Information modelling (BIM), the introduction of industrialization techniques through prefabrication, as well as automated and robotic construction processes.

Despite the incorporation of new advanced materials and techniques that aim at improving the construction performance, this sector has not been able to gain a tremendous improvement in its production system compared to other industries such as the manufacturing industry and especially the automotive industry. This is mainly due to the absence of a strategy of the renovation of the traditional management techniques [3,4]. A lot of researchers [5–8] reported that these solutions alone cannot create a significant revolution for the construction industry, especially in the absence of a solid basis of management.

Lauri Koskela is the first researcher that though in introducing the lean philosophy into the construction industry. The application of lean to construction leads to several benefits such as the optimal use of the available resources, the elimination of wastes that do not add value to the customer, people involvement, and safety improvement [9]. This concept uses only half of resources (production space, workforce resources) in order to ensure respect of the triptych (quality, cost, time) and to achieve the customers' satisfaction. However, a closer analysis of literature shows that there is a lack of a clear vision of the main practices/techniques/ tools that constitute LC concept. Consequently, most of the construction companies have applied the lean management philosophy according to their own understanding of LC principles.

The objective of this paper is to design an input-output LC model in order to provide research community better explanations of the key elements of a successful implementation of the LC approach and to show the practical contributions of LC principles in reducing all sources of wastes that exist in the construction industry.

First, current models/frameworks of LC will be analysed and synthesized. The most relevant LC principles will be identified based on a review of five reliable models that have been validated and implemented in different countries (USA, UK, Germany, Brazil, and Malaysia). Then, the practical relationship between LC principles and nine types of wastes (transportation, motion, inventory, waiting, overproduction, defects, over-processing, unused employee creativity, and work Accidents) will be investigated based on an in-depth review of related studies published in the most reliable databases.

## LEAN CONSTRUCTION MODELS

### Rapid Lean Construction-Quality Rating Model (LCR)

This model was developed in collaboration between two universities, the Brazilian University "Universidade Federal Paraná in Curitiba" and the German University Karlsruhe. It is based on six main principles (Client Focus, Waste Consciousness, Quality, Material flow & pull, Organization/ planning /info flow, Continuous improvement, Kaizen).

The LCR model takes into consideration the evaluation of the six main principles together and shows a classification scheme which helps companies identify the level of maturity of construction projects. The degree of LC-implementation made a distinction between D-projects (lowest possible level-low quality and low improvement focus, wasteful) and AAA-projects (the highest level-strive for perfection in quality improvements and LC application), as shown in Table 1.

Table 1. LCR level and results' interpretations [10]

| Result | % achieved | Interpretation of level |
|---|---|---|
| AAAA | 95% to 100% | (strive for perfection in quality improvements and LC application) |
| AA | 89% to 94% | |
| A | 81% to 88% | |
| BBB | 73% to 80% | (high-quality focus and lean-learning within the main project/company levels) |
| BB | 64% to 72% | |
| B | 55% to 63% | |
| CCC | 46% to 54% | (quality consciousness, but low/no lean-construction knowledge) |
| CC | 37% to 45% | |
| C | 28% to 36% | |
| DDD | 19% to 27% | (low quality and low improvement focus, wasteful) |
| DD | 10% to 18% | |
| D | 0 to 9% | |

**Lean Construction Maturity Model (LCMM)**

The LCM model contains eleven main key attributes (Culture & Behaviour, Customer focus, Processes & Tools, Business Results, Learning and Competency Development, Change, Work Environment, Way of Thinking, Improvement Enablers, Competencies). These key attributes can be divided into six main principles: Learning, People, Philosophy, Processes & System, Leadership, and Outcomes & Outputs, as shown in Figure 1. This model was validated through several interviews with LC experts that work as contractors, consultants, or engineers.


Figure 1. Lean Construction Maturity Model (LCMM) [11]

**Lean Construction Framework (LCF)**

Qualitative and quantitative surveys were conducted in the German construction sector to investigate the consistency between the techniques implemented and LC concepts. The survey concerns sixty-one companies that are classified among the Top 100 construction companies in Germany. A conceptual framework was developed as shown in Figure 2.

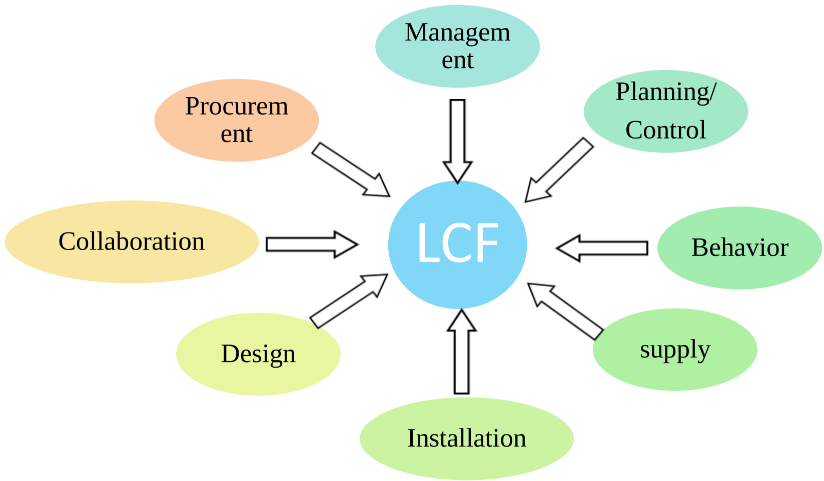



Figure 2. Conceptual Framework of Lean Construction in German construction industry [12]

**Lean Conformance Model (LCM)**

The Construction Industry Institute (CII), American organization specialized in improving the construction performance, carried out a study to identify the best practices of Lean Construction. As part of this work, the CII has developed a Lean Conformance Model, which is called Lean Construction Wheel. This model shows five main principles containing sixteen sub-principles, as illustrated in Figure 3.


Figure 3. Lean Conformance Model [13]

### Lean Construction Concept Model (LCCM)

LCCM Model outlines the most relevant concepts of Lean Construction. This model is the output of a survey carried out in the Malaysian construction industry. This study aimed at summarizing the lean construction principles in an understandable model, to assess the consciousness of the lean construction principal among Malaysian construction companies. LCC Model summarizes seven Lean constructions principles and concepts (Specify value, Identify and map the value stream, Flow, Pull, Perfection/continuous improvement, Transparency, Process variability), as shown in Figure 4.

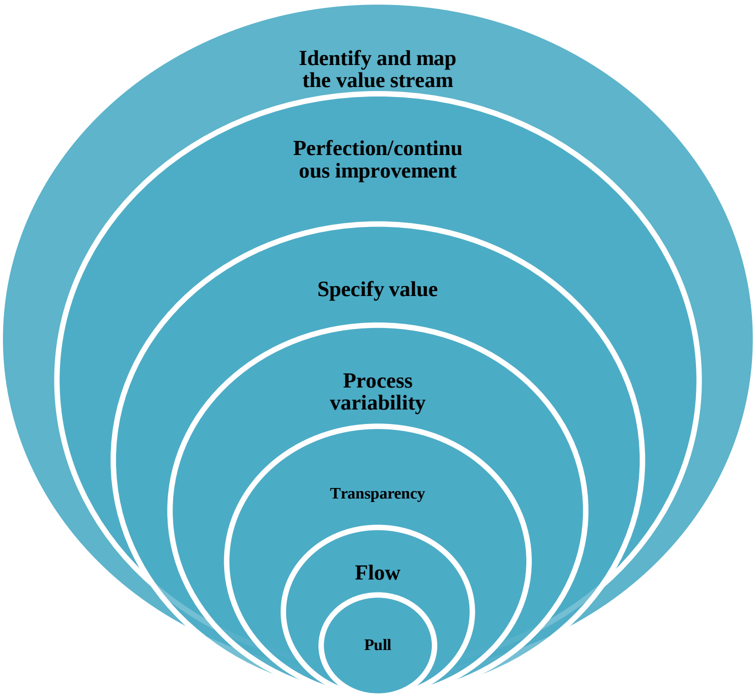



Figure 4. Lean Construction Concept Model (LCCM) [14]

## LEAN CONSTRUCTION PRINCIPLES

In order to identify the main principles of Lean Construction, we have established a critical analysis of five Lean Construction models. These models are developed in different countries which are known for their performance and maturity at the level of understanding of LC concepts (United Kingdoms, United State, Germany, Brazil...). A full scope of all models that exist in the state of art would be impractical. So, only the most widespread and the most reliable models were reviewed as illustrated in Table 2.

Table 2. Review of LC models

| No. | Authors | Model name | Objectives | Research methodology | Countries |
|---|---|---|---|---|---|
| 1 | [10] | Rapid Lean Construction-Quality Rating Model (LCR) | Evaluate the degree of leanness and the quality of a construction project through a quantitative and qualitative evaluation. | Mindmap & Brain-storming + Evaluation of 4 existing models | Germany and Brazil |
| 2 | [11] | Lean Construction Maturity Model (LCMM) | Measure the level of maturity of construction companies and make a differentiating between organizations "mature" and "immature" in LC implantation. | Interviews | UK |
| 3 | [12] | Lean Construction Framework (LCF) | Qualitative and quantitative surveys were conducted to investigate the current understanding of Lean construction principles among German contractors. | Questionnaires | Germany |
| 4 | [13] | Lean Conformance Model (LCM) | Identify the best practices and the most commonly used principles of Lean Construction among the members of The Construction Industry Institute (CII). | Questionnaires and case studies | USA |
| 5 | [14] | Lean Construction Concept Model (LCCM) | Summarize the most relevant Lean Construction principles and concepts. | Literature study | Malaysia |

Based on the analysis of the above-mentioned models we identify nine main principles that represent the basis of Lean Construction approach and which are: Customer focus, Supply, Continuous improvement, Waste elimination, People involvement, planning and Scheduling, Quality, Standardization, Transparency, as shown in Table 3.

Table 3. The main principles used in LC models

| | LCMM | LCCM | LCR | LCF | LCM |
|---|---|---|---|---|---|
| Customer focus | ✓ | ✓ | ✓ | ✓ | ✓ |
| Supply | | ✓ | ✓ | ✓ | |
| Continuous improvement | ✓ | ✓ | ✓ | | ✓ |
| Waste elimination | ✓ | ✓ | ✓ | | ✓ |
| People involvement | ✓ | | | ✓ | ✓ |
| Planning and Scheduling | | | ✓ | ✓ | |
| Quality | | ✓ | ✓ | | |
| Standardization | | | ✓ | | ✓ |
| Transparency | ✓ | ✓ | | | |

In addition, these principles can be divided into three primary pillars:

- Systems management: it focuses on the management of systems in interaction with customers, suppliers, and contractors (Customer focus, Supply, Planning and Scheduling);
- Technology management: It concerns the operational techniques aimed at optimizing the performance of the company (Transparency, Standardization, and Quality);
- Culture and behaviour: This pillar encompasses all Lean Construction practices that allow the dissemination of a culture of continuous improvement during all cycle of production while ensuring an optimal use of employee skills (people involvement, continuous improvement).

These three pillars are based on eliminating waste which is the core of the lean construction philosophy, as illustrated in Figure 5.

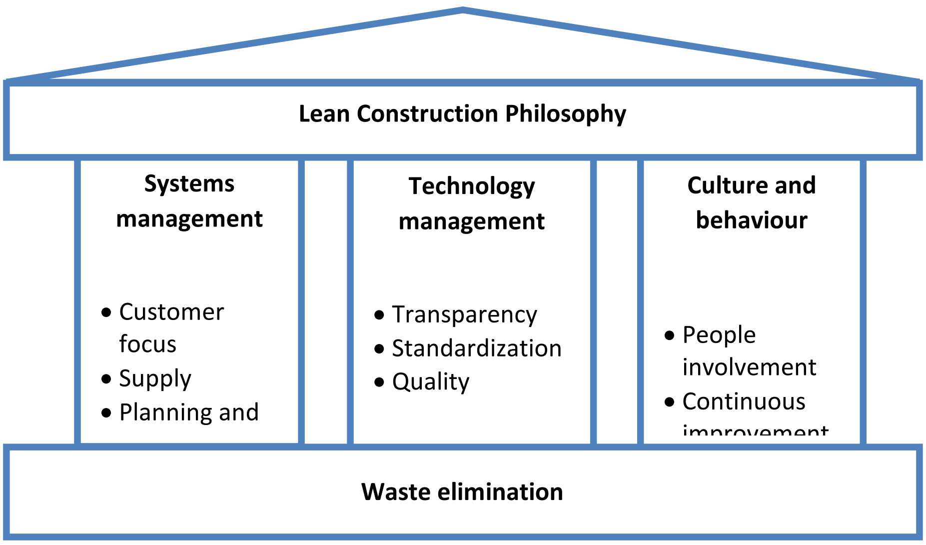



Figure 5. Main pillars of Lean Construction philosophy

## PRACTICAL RELATIONSHIPS BETWEEN LEAN CONSTRUCTION PRINCIPLES AND SOURCES OF WASTE

The sources of wastes are defined as activities/tasks that consume the resources of the company but don't generate the value for internal or external customers [15]. The seven forms of waste identified by Toyota, which are known as the seven Muda, are as follows: Transportation, Motion, Inventory, Waiting, Overproduction, Defects, defects and Over-processing [5]. Several researchers have added "Unused employee creativity" as the eighth source of waste [16–18]. Recently, professionals and researchers interested in improving working conditions within the construction site have begun to emphasize the importance of reducing the accident rate and therefore they consider work accidents as the ninth source of waste [19–22]. In this section, we focus on identifying the practical relationship between LC principles that we've determined previously, and the nine types of wastes existing in the construction sector.

### Transportation

Transportation activities concern the movement of materials between the different workstations as well as the established travel using the crane. These actions don't add value to the final product; instead, it caused an increase in the time of the production cycle, an inefficient use of working space and labour. Table 4 shows practical contributions of LC principles in reducing transport actions.

Table 4. Practical contributions of LC principles in reducing transport actions

| Principles | Practical contributions | Authors |
|---|---|---|
| Supply | The success of construction projects depends largely on the ability of the project team to organize its logistics flows (delivery/handling of materials and equipment in the construction site) on the basis of the just-in-time philosophy. | [23] |
| Waste elimination | LC practices/techniques such as (VSM, Cycle time reduction, etc.) allow identifying logistic flow weaknesses so that helps locate points requiring improvement in order to reduce waste due to transport actions. | [24] |
| Standardization | The standardization of transport methods makes logistics flow more reliable and reduces hazardous transport actions that generate waiting times. | [25] |
| Transparency | A transparent and well-organized workspace identifies the areas of handling path to avoid blocking the flow. | [6] |

**Defects (Non-Quality)**
Quality defects are considered a double source of waste generation, either in terms of the resources (labour, materials, equipment) to be implemented or on the level of turnover not generated during the entire repair period. Besides, defects have a negative effect on the synchronization of the planned tasks, the organization within the construction site and on the motivation of staff to repeat what has already been done in addition to the penalties [5]. Table 5 shows practical contributions of LC principles in reducing quality defects.

Table 5. Practical contributions of LC principles in reducing quality defects

| Principles | Practical contributions | Authors |
|---|---|---|
| Customer Focus | The ability to adapt to the changes proposed by the customer allows building with the minimum of defects, especially in the design phase. | [26] |
| Continuous improvement | The continuous improvement of constructive methods and materials used allows companies to avoid the recurrence of the defects resulting from obsolete working methods. | [5] |
| Waste elimination | The staff awareness of the criticality of quality defects on the profitability of the company promotes a mutual responsibility to avoid the occurrence of such failures. | [27] |
| People involvement | Employee involvement in the problem-solving phase can generate creative solutions that reduce the frequency of occurrence of defects. | [6] |
| Planning & Scheduling | LPS allows accomplishing the planning of tasks according to the moral and physical capacity of the labors which minimizes the defects that are generated in the case of complex and too hard works. | [28] |
| Quality | The concept of quality is based on control sheets for safety monitoring, Poka Yoke devices to avoid intentional errors, and various problem-solving techniques such as (Brainstorming System, Ishikawa, Pareto, The five why ...) | [29] |
| Standardization | Standardized construction processes reduce the occurrence of quality defects that are due to operator hazardous actions as well as standardized repair operations decrease the time spent during maintenance work. | [30] |

**Waiting**

Waiting is the direct results of a bad synchronization of the planned tasks, the absence of (materials, manpower, validation, plan, information) that are necessary to perform the required work or even the failure of equipment [6]. In the traditional system of construction project management, most of the time spent on construction sites is wasted in the form of waiting times. According to the study conducted by Dupin [5] the waiting time in construction projects goes to 29%; it represents the largest share of time spent on the construction site. Table 6 shows practical contributions of LC principles in reducing waiting times.

Table 6. Practical contributions of LC principles in reducing waiting times

| Principles | Practical contributions | Authors |
| --- | --- | --- |
| Customer Focus | An organization with flexible production resources is more likely to satisfy the changes proposed by the customer all through the cycle of construction as best as possible and with the minimum of waiting times. | [31] |
| Supply | The system just in time-based on the use of Kanban cards and the Organization of work in a pull-flow supply system flow minimizes significantly waiting times due to the lack of materials by late orders, out of stock... | [5] |
| Waste elimination | Waste elimination strategies aimed at process optimization (VSM, Cycle time reduction, etc.) contribute to the identification and elimination of waiting times. | [32] |
| Planning & Scheduling | The last Planner System contributes in improving the reliability of planning in such a way to keep the scheduled task with almost zero constraints so that minimizes waiting times. | [6] |
| People involvement | The availability of multi-skilled employees helps companies avoid the blockage of the flow especially in the absence of an operator or lack of a required competence for the execution of the tasks. | [33] |
| Transparency | A good organization of the workstation with the 5S approach and visual management allows reducing waiting times that are owed in search of working materials/tools. | [10] |

**Inventory**

The amount of storage on-site is an indicator of the level of waste, especially with a push-flow supply system. In fact, materials and materials stored and which will not be used in the short term, are the source of several negative effects for the company such as storage costs, scarcity of free space. As well as the degradation of materials stored under the effects of bad weather. Table 7 shows practical contributions of LC principles in reducing the inventory.

Table 7. Practical contributions of LC principles in reducing inventory

| Principles | Practical contributions | Authors |
|---|---|---|
| Supply | A large amount of on-site storage is the result of a push-flow supply system. Contrary to this vision, the philosophy of the LC is based on a system of pull-flow supply system which allows ensuring only the quantity really demanded in the stocks. Several techniques are deployed to achieve this objective such as kanban cards, supply chain management (SCM), preparation J-1. | [5] |
| Waste elimination | Value Stream Mapping (VSM) helps to identify critical storage areas that contain materials or construction tools that will not be used in the short-term construction process. | [34] |
| Planning & Scheduling | LPS made the correlation between planned work and quantity of (materials/equipment) available on stock in such a way not to have either an overstocking or a lack of materials in stock | [35] |
| Standardization | Several projects based on the supply of prefabricated and standardized elements have shown that this technique helps to keep a minimum level of storage of raw materials. | [36] |
| Transparency | The 5S process and visual management make it easier to manage the storage area and reduce the space occupied by the stored materials. | [10] |

**Over-processing**

Over-processing or too complex process, this type of waste concerns tasks and unnecessary extra work. This also includes tools that are more accurate, complex or costly than is necessary. Additional unnecessary work is considered as a waste that increases the cost of production and does not add value to the final product of construction [27]. Table 8 shows practical contributions of LC principles in reducing over processing.

Table 8. Practical contributions of LC principles in reducing over processing

| Principles | Practical contributions | Authors |
|---|---|---|
| Continuous improvement | Continuous improvement allows thinking of more optimal, simple and efficient work methods and instructions. | [10] |
| Waste elimination | Complex processes are critical to the quality of the final product, the construction time, the cost invested in the project. The awareness of personnel of the criticality of this problem allows proposing simpler and less expensive solutions. | [5] |
| Planning & Scheduling | The choice of methods work by the last planner minimizes the instructions or specifications not clear and not standardized. | [33] |
| Standardization | Clear and standardized instructions or specifications contribute significantly in reducing over processing. | [37] |

**Overproduction**

Overproduction is to produce more than what is required by the customer or even build structures that will not be used and will be intended to be destroyed in the short term. The following table shows the practical contributions of the LC concepts in reducing overproduction. Table 9 shows practical contributions of LC principles in reducing overproduction.

Table 9. Practical contributions of LC principles in reducing overproduction

| Principles | Practical contributions | Authors |
|---|---|---|
| Customer Focus | Integrating the customer into the value-added process reduces unnecessary activities, so the production chain focuses only on what is requested by the customer. | [38] |
| Supply | The use of LC practices (Just-in-time/SCM/Pull system/Customer involvement) is designed to determine in detail the necessary resources for the construction process (labor, equipment, materials, space) just at the time of need | [5] |
| Waste elimination | The culture of waste elimination helps the company to identify non-value added processes as well as to determine the roots of the overproduction causes. | [33] |

**Motion**

This waste concern moves of operators, materials, and hardware that add no value to the cycle of production. On the contrary, they increase the difficulty of work for labor and increase the use of space. According to Dupin [5], a worker in the construction building walks between seven and nine kilometers. These displacements are due to several factors such as the research of equipment, raw materials, a plan or information, moving from one work area to another and so on. Table 10 shows practical contributions of LC principles in reducing motion.

Table 10. Practical contributions of LC principles in reducing motion

| Principles | Practical contributions | Authors |
|---|---|---|
| Supply | An efficient logistics flow management system ensures the availability of all the necessary elements for construction processes (materials, tools, etc.) which minimizes unnecessary movements between the stock and workstations. | [39] |
| Waste elimination | Cycle time minimizing imperatively requires reducing the time spent on unnecessary travel. | [6] |
| Transparency | Visual management techniques make it easy to identify the locations of the different elements (raw materials, Tools, etc.) using signalling techniques. In addition, the 5S process reduces unnecessary travel by keeping everything in its proper place. | [5] |

**Unused employee creativity**

It is the eighth source of wasting. This type of waste characterizes traditional systems of production [40]. The orders are given by the section engineers and little place remains for the initiative and creativity, neither individual nor collective. According to several previous study [6,41–43], human potential can be considered as an important source of creative solutions to solve the root causes of problems within the construction company. Table 11 shows practical contributions of LC principles in reducing wastes generated in the case of unused employee creativity.

Table 11. Practical contributions of LC principles in reducing unused employee creativity

| Principles | Practical contributions | Authors |
|---|---|---|
| Continuous improvement | Continuous Improvement culture promotes the participation of all the actors of the project and especially the labor. Indeed, the PDCA (Plan, Do, Check, Act) approach cannot achieve its objectives without human creativity. | [44] |
| Waste elimination | The consciousness of the criticality of non-added value tasks motivates the integration of labour in the process of identifying and eliminating wastes. | [45] |
| People involvement | People involvement is essentially intended to incorporate the employees through training, meetings, and so on which motivate them to participate in improving the project performance. | [46] |
| Quality | Several techniques such as Brainstorming System, Ishikawa, and the five why are based on the potential of employees to generate maximum creative solutions. | [47] |
| Planning & Scheduling | Last Planner System is a participatory planning tool that considers the staff as the most reliable source of a realistic plan especially as they are the closest to the actual constraints and working conditions in the construction site. | [48] |

**Accidents**

Injuries and fatality are considered as the ninth source of waste [20–22,49–51]. The death or injury of labours leads to a loss in the process reliability and creates additional costs such as insurance costs, high medical treatment costs, and a rehabilitation program. In addition to that, poor conditions of work generate indirect losses such as a decrease in productivity as well as the reduction in staff motivation [21]. Table 12 shows practical contributions of LC principles in reducing accidents on construction sites.

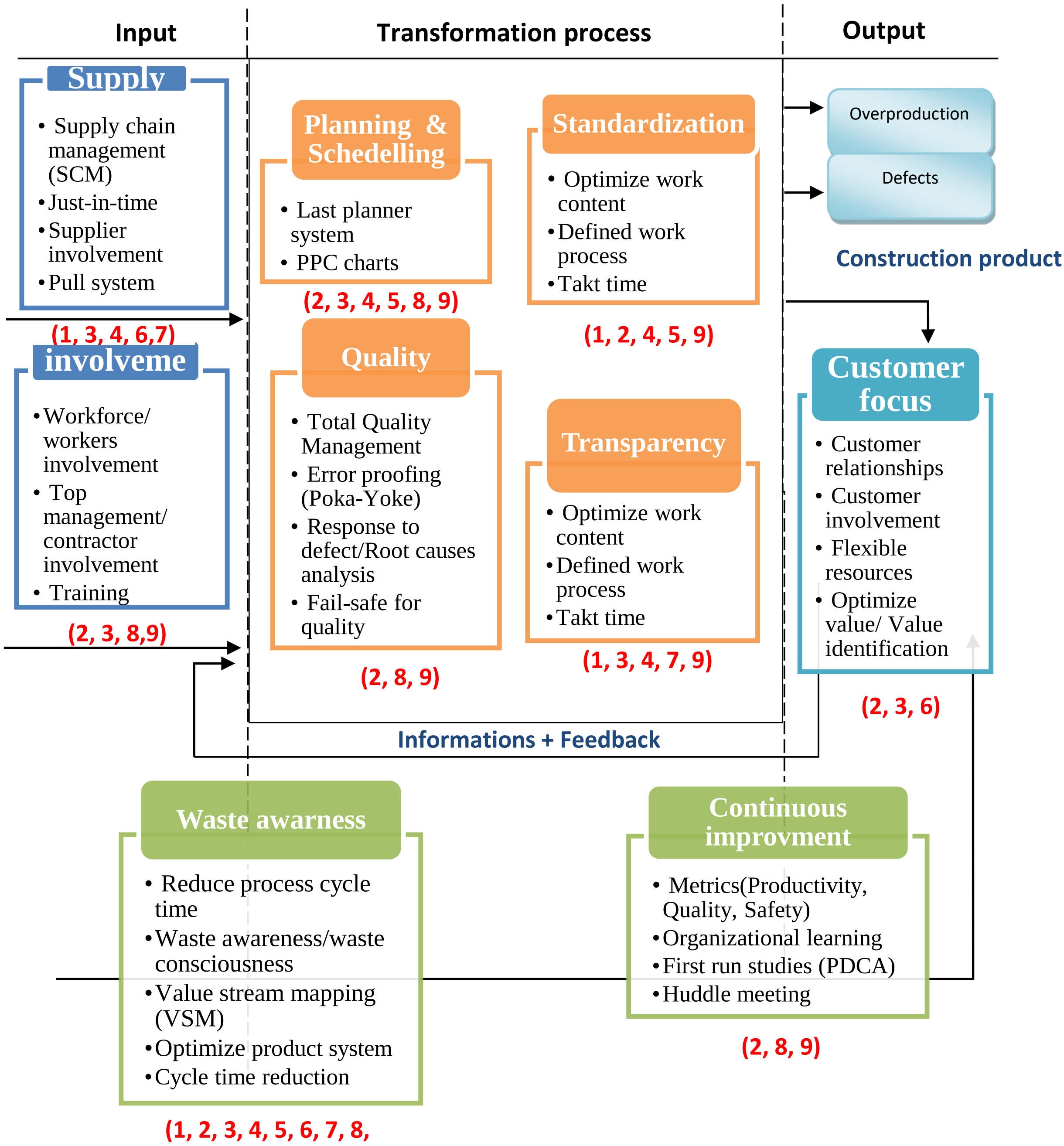
Table 12. Practical contributions of LC principles in reducing work accidents

| Principles | Practical contributions | Authors |
|---|---|---|
| Continuous improvement | Improving on-going performance indicators is a major pillar of continuous improvement. The accident rate is one of the most important indicators within the construction site, and that needs the implementation of precautions to reduce it to the minimum possible. | [50] |
| Waste elimination | The consciousness of the criticality of accidents on construction sites makes the workforce more cautious in terms of compliance with the safety instructions. | [19] |

| | | |
|---|---|---|
| People involvement | The incorporation of the staff in the safety management allows reducing the rate of accidents through training, daily meetings… | [51] |
| Planning-Scheduling | The empowerment of employees to commit themselves to the tasks they could perform over a period of time contributes tangibly to the reduction of accidents. Moreover, the Last planner system involves the continuous monitoring of the process flow in such a way to maintain the correlation between the skills of workers with tasks scheduled. Moreover, the implication of labors in the selection of the construction methods, which correspond to their capacity, could increase the motivation of the staff and, consequently, the accidents related to the mental issues and excessive stress could be minimized. | [49] |
| Quality | Qualitative tools such as Brainstorming System, Ishikawa, and the five why help to identify the root causes of workplace accidents. In addition, Poka-yoke devices are considered an innovative manner to avoid unintentional errors by launching an alarm in case of danger or even stop the process in progress. Furthermore, these gadgets prevent employees from crossing or approaching from dangerous places (excessive heat, noise, dust, falling objects, concrete elements waiting for drying ...) through an audible or luminous alarm. | [25] |
| Standardization | Let the operators perform dangerous tasks (Cutting, drilling, and casting of concrete) with their own way which increases the risk of injuries and deaths at construction sites. Indeed, the use of standardized processes minimized the level of hazardous action which helps companies reduce the occupational accidents. | [52] |
| Transparency | A poorly organized workplace is classified among the main causes of accidents on the construction site. The 5S approach and visual management lead to a well-organized construction site which promotes the safety and the productivity of the workforce. | [40] |

## DEVELOPMENT OF AN INPUT-OUTPUT MODEL OF LEAN CONSTRUCTION

Generally, the construction system is an input-output model. This system contains as input the components needed to start the transformation stage in order to reach the construction product at the end respecting the deadline, the cost of the project and minimizing all types of waste. As illustrated in Figure 6, we have developed an input-output model adapted to the construction context.




*1: Transportation 2: Defects (Non-Quality) 3: Waiting 4: Inventory 5: Ove- processing 6: Overproduction 7: Motion 8: Unused employee creativity 9: Accidents.*

Figure 6. An Input-output model illustrating the practical relationships between LC principles and sources of waste

This model is based on the main principles which we have determined by analysing the most reliable models dealing with the implementation of the Lean Construction philosophy. In addition, Figure 6 shows LC techniques and tools that could be used by construction companies to reduce each type of waste. People Involvement and Supply constitute the basis of the input phase because they ensure all the sources necessary to begin the transformation phase (labour, materials, equipment...).

The transformation process contains four main principles: Quality, Planning & Scheduling, Standardization, and Transparency. These principles are intended to respect the triptych (quality, cost, time) while ensuring the best conditions of work for labours.

Customer focus plays a major role in the output phase by transferring information and feedback to the input phase. This operation remains valid throughout all the cycle of the project (design, Construction, delivery) which make it possible to reduce the generation of construction infrastructure not requested by the customer (overproduction), or the appearance of defects in the construction product at the delivery phase (defects).

Waste elimination and continuous improvement are integrated throughout the construction cycle, starting from the beginning to the end of the project. They are important for the performance of construction projects during the three stages of the project (Input phase, Transformation phase, Output phase). In addition, these two concepts make it possible to ensure the permanent improvement of (quality, cost, time) and to replace the traditional management techniques by a rigorous and systematic approach of waste reduction. Figure 6 also shows the practical relationship between the principles of Lean Construction and all forms of waste (Transportation, Motion, Inventory, Waiting, Overproduction, Defects, defects, over-processing, unused employee creativity, and accidents).

## CONCLUSION

This work was intended to provide an input-output model that shows the principles of Lean Construction. Initially, the most relevant principles have been identified, based on models that have been applied in several countries (USA, UK, Malaysia, Germany and Brazil). Nine principles have been identified (Customer focus, Supply, Continuous improvement, Waste elimination, People involvement, planning and Scheduling, Quality, Standardization, and Transparency).

In addition, the practical relationships between those principles and the different sources of waste (Transportation, Motion, Inventory, Waiting, Overproduction, Defects, Over Processing, Unused Employee Creativity, and Work Accidents) have been investigated based on a rigorous review of the best-known bibliographic references published in several databases as DOAJ, ISI Web of Science, and Scopus. This research leads to a better understanding of Lean Construction principles.

Moreover, this work can help construction companies choose the most appropriate techniques for each type of waste. In perspective, further researches, especially empirical studies, are needed to test, validate, and improve the proposed theoretical input-output model.

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