Fuenzalida, C. Fischer, B., Arroyo, P., and Salvarierra, J. L., (2016). "Evaluating Environmental Impacts of Construction Operation Before and After the Implementation of Lean Tools." In: *Proc. 24th Ann. Conf. of the Int'l. Group for Lean Construction*, Boston, MA, USA, sect.10 pp. 3–12. Available at: <www.iglc.net>.

EVALUATING ENVIRONMENTAL IMPACTS OF CONSTRUCTION OPERATION BEFORE AND AFTER THE IMPLEMENTATION OF LEAN TOOLS

Camila Fuenzalida[1], Benjamín Fischer[2], Paz Arroyo[3] and Jose L. Salvatierra[4]

ABSTRACT

Construction industry has a fundamental role in the impact caused to the environment, both during construction and operation. In this research three Lean tools - Ishikawa Diagram, 5 whys, and A3 reports- were carry out at construction site during wall and floor ceramic installation. The aim was to investigate whether the application of Lean tools improved productivity in the activity execution, and measure the environmental benefits obtained. The research methodology included analysing video recordings of the activity execution, working groups with workers and management, and training for using Lean tools. From this, it was show that the principal perceived waste was rework and its cause was lack of control. Furthermore, it was prove that these Lean tools' implementation reduces carbon dioxide emissions, for installing walls and floor ceramic, considering a reduction in the use of materials needed for the evaluated activity. In conclusion, Lean tools' implementation allows reducing environmental impact by concentrating reduction efforts on the most important activity wastes.

KEYWORDS

Lean construction, productivity, environmental impacts, wastes.

INTRODUCTION

Construction industry has high environmental impact because of construction itself and the building's later use and occupation throughout its lifetime. Lean Construction (LC), or construction without wastes, is an approach for construction management and

[1] Master Student, Construction Engineering and Management Dept., School of Engineering, Pontificia Universidad Católica de Chile, Santiago, Chile, +569 56189350, cpfuenzalida@uc.cl

[2] Student, Construction Engineering and Management Dept., School of Engineering, Pontificia Universidad Católica de Chile, Santiago, Chile, +569 56189350, befischer@uc.cl

[3] Assistant Professor. Pontifical Catholic University of Chile, +56 22354-4244, parroyo@ing.puc.cl

[4] Research, Development and Innovation Manager, the Production Management Centre of the Pontifical Catholic University of Chile - GEPUC. Av. Vicuña Mackenna 4860, Edificio Mide UC, 3er piso, Macul, Santiago, Chile, Phone +56 2 2354 7039, jsalvatierra@gepuc.cl

production based on the production system used by Toyota. LC's goal is making processes more effective and designing production systems minimizing resources' loss to attack the stagnation problem and low productivity.

Lean in construction industry promotes continuous improvement throughout wastes reduction and value increase for the client. Considering wastes, everything that corresponds to time wasted, unnecessary work, wasted resources, and other activities that do not add value to final product.

Construction area has a great amount of activities that do not add value in its processes and that leads to low productivity. Thus, introducing new production techniques that aim for continuous improvement can be important in construction productivity and quality. Some Lean tools are the Ishikawa Diagram, the 5 why's analysis and the A3 report.

The Ishikawa diagram is a representation of a cause-effect analysis that carried out for any type of result. This diagram allows sort and classify all different causes for a certain effect. Ishikawa is for recognize the important causes generating an effect to influence over them and change the effect it is causing.

The 5 why's analysis is carried out to identify the root cause that generated the effect. It works by asking once why the effect happened, and to the response of that question, ask again, why it happened. Same proceeding is repeated until asking five times why it happened and by the end of the process, the answer is the root cause. Root cause must be modified in the case of wanting to alter the effect produced. For instance, in the case the effect is a problem that we do not want to keep repeating, to eliminate it we must act upon the root cause instead of generating short-term solutions.

The A3 report is a way of representing an action course, in which goals, methodology, agents involved and others are included. It is done in an A3 sheet to have a plan' summary set to carry out and to make periodical updates according to progress made and results.

This study presents an explanation to methodology and results of an investigation carried out in the context of the collaborative group GEPUC "Constructing Excellence". The principal goal is to apply Lean tools in construction site and measure the change in environmental impact that these tools allow because of a change in resources usage. Environmental impact will be measured in equivalent carbon dioxide' kilograms (kg of CO_2-eq). It is important to notice that emissions quantified correspond only to materials used. A more detailed analysis could incorporate the emission due to labour working hours. Specific goals are i) teach investigation participants' LC concepts, ii) identify frequent wastes and their cause, iii) qualify participants in three Lean tools application, iv) Create an audio-visual record of a critical work' execution and v) determine carbon dioxide emissions produced by using materials.

RESEARCH METHODOLOGY

The research consisted in the intervention of a particular site built by a construction company. In this site, we selected the installation of tiles to analyse. The people involved were seven; there was the project manager and other participants. Phases that makes up the investigation are present in Figure 1.

Figure 1: Phases of the investigation

VISIT 1 TO THE PROJECT

First, visit 1 to the site chosen by the company was carry out. In this session, participants were introduce to the concepts of value and waste, and a workshop took place to identify wastes existing in the site. The workshop consisted on four polls. The first one required participants to identify main wastes at the worksite. In the second one, the partakers should figure the causes of these wastes. The third poll was looking for the participants to match each type of waste to its main cause. The last poll consisted in identifying the five most common wastes and assigning them a relevance level according to individual perceptions. These four polls were carried out for a particular set of traditional construction wastes and another set of wastes strictly linked to environmental impacts.

After the workshop, there was a training in the three Lean tools implementation and a work in execution' recording took place (1 h) were it was possible to identify wastes and their causes.

After visit 1, the information was analysed through videos recorded and the polls' results. Besides, companies were asked to send information about the chosen work' yield and output so with this information, an analysis of most frequent losses and causes started.

ROUNDTABLE

Second, a roundtable was carry out were the project managers of each site participated (see Figure 2). In this meeting, visit 1' results were exposed and the A3 report elaboration was set in motion as to summarize the action course to apply Lean tools on the actual site.

Figure 2: Project Managers at the roundtable

VISIT 2 TO THE PROJECT

Third, there was a visit 2 at the site of each company. In this instance, a recording of chosen work took place for about 1 hour to identify improvements applied. Besides, a second poll was carry out to each person involved, this tried to clarify the participants' perception on the improvement obtained and raise awareness that the workshop brought the workers. At this, we asked managers to give new productivity measurements achieved after applying the action course with the investigation's Lean tools.

QUANTIFICATION OF IMPACT

In this phase, the recollected information through a second poll and recording was analysed. Then it was carried out the environmental impact' quantification provoked at the first recorded performance in comparison to the final achieved. We used this information to quantify the mass of CO_2-eq. emitted in each scenario.

CLOSURE REUNION

In the closure reunion was an exposition of obtained results to project managers and each company's important executives. In this instance, a conversation rose about the good praxis of each company to set an example for each other.

RESULTS AND DISCUSSION

First phase results about polls and waste detection workshop we will present. Then, second phase results about environmental impact quantification during work execution will be shown. Finally, there is going to be an interpretation of both sets of results.

PHASE 1 RESULTS

In the first poll carried out in the workshop that was registered through filming, it was decided that the most frequent wastes are work remade, error done throughout work and delay of activities.

Second poll' results are illustrating each cause of waste and the percentage of the team mentioned it as frequent (Figure 3). The results showed that no one named "excess of bureaucracy" as waste, while 86% of the team mentioned a lack of control and workforce as frequent wastes.

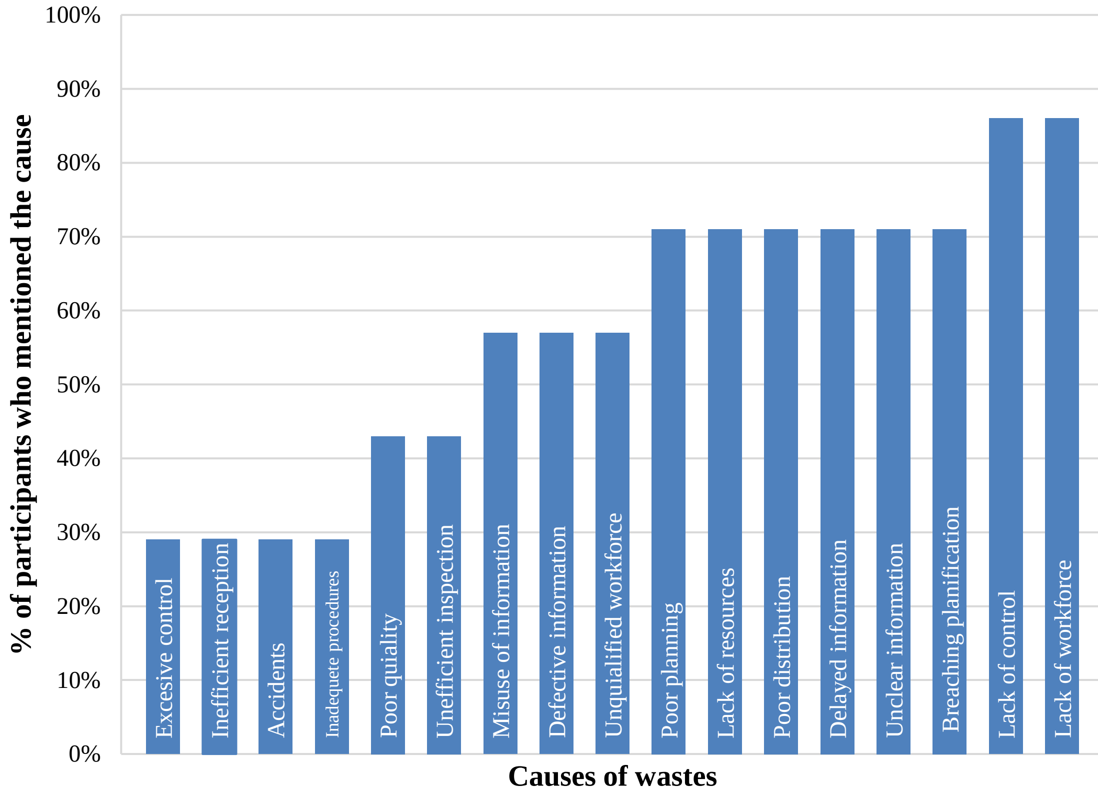

Figure 3: Frequent causes of waste identified by participants

In the third poll, the more frequent relations between wastes and its causes are work remade because due to lack of control, delay in activities by bad planning, work remade because unclear information, and work not done because a lack of workforce. About waste linked to environmental and social impact, the most frequent waste was loss of materials because lack of control.

Finally, final poll results' sets that the most important traditional type of waste for the participants' majority is work remade (see Figure 4). This waste was classified as important by the seven participants and got a score of 3,85 in average (where 0 is non-important and 5 is very important). The results on environmental and social wastes showed that the most important and frequently named by participants is material loss that is throwing away not used materials. This waste is identified as important by all of the participants with an average score of 3,14 out of 5 (see Figure 5).

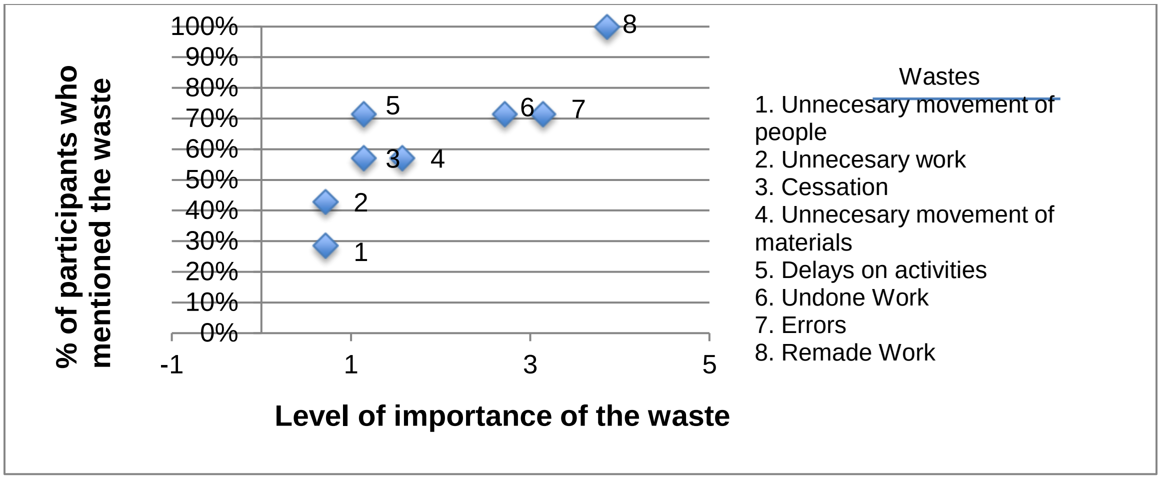

Figure 4: Level of wastes importance

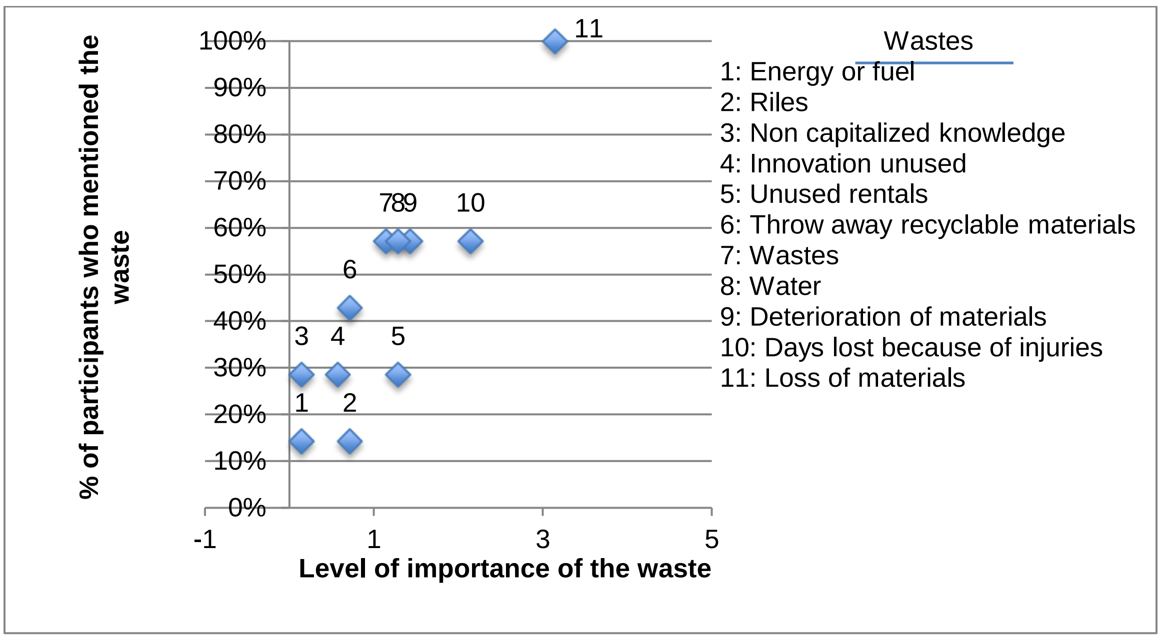

Figure 5: Level of environmental and social wastes importance

After analyse results in phase 1 we established that in construction sector exists many losses recognizable by those involved in the work. These losses have their causes that are because the job runs bad in suboptimal conditions. To avoid occurrence has to be a work execution' good planning to predict and control losses. Other lean tools and methods such as Last Planner System could help to reduce these wastes. However, that is out of the scope of this research.

PHASE 2 RESULTS

In phase 2 includes the environmental impact analysis generated by the installation of ceramics on walls and floors. We quantified this impact calculating the carbon dioxide emissions by the type and amount of material used in this work.

We present results and interpretation for first, ceramics used in walls; second, for the adhesive used in walls; and third, for ceramic and adhesive for the floor.

In table 1, we present the emissions of ceramics for walls. To understand the results, the calculation to obtain the first week' real emissions are shown in the study. The amount of ceramics used were 416 m^2, this is multiplied by emissions to produce 1 m^2 of ceramic walls that are 15.9 kg /m^2 [6]. This result in 6,614.4 kg of CO_2 -eq emitted for producing ceramics. To calculate the ideal emissions it is necessary to consider the geometric area covered with ceramic. Emissions without intervention were calculated taking into account that during the five weeks performance was the same that in the first one. Finally, for emissions with best performance we considered that work done during 5 weeks with the best-reached performance. For example, to calculate emissions without intervention we took week 1 performance, equal to 0.904. Thus, we divided the geometric area (376.15) by 0.904, obtaining 416.1 m^2 of ceramic. Then, multiplied this area by 15.9 kg/m^2 getting 6,615 kg of CO_2 -eq emitted.

Table 1: Summary of emissions per week for ceramics of walls

Emissions for ceramics of walls (kg CO_2-eq.)				
	Real emissions during the work	**Ideal Emissions (with optimal performance)**	**Emission without intervention (considering performance of week 1)**	**Emissions with best performance reached**
Week 1	6,614.40	5,980.79	6,615.91	6,004.80
Week 2	1,894.64	1,733.26	1,917.32	1,740.22
Week 3	3,192.08	3,178.09	3,515.59	3,190.86
Week 4	2,690.28	2,517.61	2,784.96	2,527.72
Week 5	520.88	477.80	528.53	479.71
Total	14,912.29	13,887.54	15,362.32	13,943.31

The gap between real and ideal emissions is 1,024 kg CO_2-eq that is a magnitude measure of the improvement generated if losses reduce to zero. The gap between real emissions and emissions without intervention is 450 kg CO_2-eq. we attribute this to Lean tools' implementation contemplated in this investigation. Although, it cannot be certain because may be other uncontrolled external factors, such as personnel change, that could influenced outcome. Anyway, after lean tools' were implemented an increase in performance was evident, being the best performance in the third week. If this performance were every week performance, they would have stopped issuing 969 kg of CO_2-eq. This results' interpretation is replicable for cases of adhesive and ceramic used.

In table 2, we present the emissions for the adhesive used for the installation of ceramics in walls. The optimal performance for adhesive recommended by the producer is 1.6 kg /m^2 per millimetre of thickness. The average thick used in walls is about 3 mm, thus the optimal performance is 4,8 kg /m^2.

Table 2: Summary of emissions per week for adhesive used in walls

Emissions for adhesive of walls (kg CO_2-eq.)

	Real emissions during the work	Ideal Emissions (with optimal performance)	Emissions with best performance reached	Emission without intervention (considering performance of week 1)
Week 1	447.10	283.24	343.66	447.10
Week 2	193.49	94.18	114.28	148.67
Week 3	229.51	172.70	209.54	272.61
Week 4	220.51	136.81	165.99	215.95
Week 5	31.50	25.96	31.50	40.98
Total	1,122.11	712.89	864.97	1,125.32

Table 3 shows the emissions by the ceramics used for the floor. In week 5 the work was finished, thus no materials used.

Table 3: Summary of emissions per week for ceramics of walls

Emissions for ceramics of walls (kg CO_2-eq.)

	Real emissions during the work	Ideal Emissions (with optimal performance)	Emission without intervention (considering performance of week 1)	Emissions with best performance reached
Week 1	5,810.17	5,293.73	5,810.90	5,390.76
Week 2	2,188.95	2,089.38	2,293.50	2,127.68
Week 3	1,433.58	1,407.24	1,544.72	1,433.03
Week 4	875.71	881.18	967.26	897.33
Week 5	0.00	0.00	0.00	0.00
Total	10,308.41	9,671.52	10,616.38	9,848.80

In table 4, we present the emissions for adhesive used in ceramics for floor. In this case, we considered 5 mm thickness of adhesive; thus, the optimal performance recommended by the producer is 8 kg/m^2.

Table 4: Summary of emissions per week for adhesive used in floors.

Emissions for adhesive of walls (kg CO_2-eq.)				
	Real emissions during the work	**Ideal Emissions (with optimal performance)**	**Emissions with best performance reached**	**Emission without intervention (considering performance of week 1)**
Week 1	1,271.70	574.62	1,192.98	1,271.70
Week 2	571.50	275.27	571.50	609.21
Week 3	405.01	185.40	384.91	410.31
Week 4	310.50	116.09	241.02	256.93
Week 5	0.00	0.00	0.00	0.00
Total	2,558.71	1,151.38	2,390.41	2,548.15

Analysing the results we can establish that emitted emissions may reduce to reach the ideal point. This would mean that processes are performing in the best way possible and that work is without losses or inefficiencies. However, all processes have necessary activities that do not add value for the client, thus present losses cannot reduce in 100%. Yet, the results show that emissions can reduce significantly with a good Lean tools' implementation. Importantly, these tools must be correctly implemented and with great monitoring, to promote a culture of continuous improvement throughout the project. Lean tools are not self-supported without a transverse effort of the organizations' culture and philosophy. This means those involved in the work, executive positions to operational, must be present in the intervention and improvement process, so they can improve and increase activities productivity through implemented mechanisms.

CONCLUSIONS

This research showed that exists a potential in Lean tools' implementation that can benefit productivity and reduce CO_2 emissions. Because of this, we recommend to enterprises to spend time and resources in these initiatives to create a culture where loss reduction and value creation is constant. People involved in this research are able to see this type of tools' usability, so it is possible create organizations where continuous improvement is part of their daily processes. This adds to the benefit that such actions can generate in the ecosystem through a resources reduction needed for each project.

To get improvements we recommend to companies conduct internal workshops based on concepts of loss and value, identifying the most common losses and their sources. Then, from the findings, implement corrective measures to eliminate all or part of frequent losses. It is necessary to communicate the corrective measures carried out to everyone involved at the work to create an awareness of continuous improvement. In addition, encouraging other projects to apply what they learned to generate knowledge. Continuous improvements are necessary to promote mechanisms for periodic quantification of loss reduction, and to encourage it with incentives to the most productive groups to align the objectives of all parties involved.

This study has identified that Lean and its associated tools remain superficially used by companies. Key concepts, value and losses, are not part of a common language that account more efficient and friendly environmental organizations. We proposed that future research must focus on the generation of common language on each organization, creating a culture inspired by change and continuous improvement. This research can also be expanded by studying other lean tools and methods and by including environmental impacts related with labour and equipments.

ACKNOWLEDGMENTS

We would like to thank for the participation of construction enterprises of the collaborative group of GEPUC for giving us access to their job sites and data for investigation

REFERENCES

Aislantes Nacionales (n.d). "Bekron". <http://www.aislantesnacionales.cl/pdfs/bekron.pdf> (April 4, 2016)

Alarcon, L.F. (2001). "Identificación y Reducción de Pérdidas en la Construcción: Herramientas y Procedimientos". Lom ediciones Ltda.

Chou, J. and Yeh, K. (2015). "Life cycle carbon dioxide emissions simulation and environmental cost analysis for building construction". *Journal of Cleaner Production*., 101, 137–147.

Hang, T. and Domfeld, D. (2007). "Energy Use per Worker-Hour: Evaluating the Contribution of Labor to Manufacturing Energy Use". *Proceedings of the 14th CIRP Conference on Life Cycle Engineering*, Waseda University, Tokyo, Japan, June 11th–13th, 2007.

Liker, J. (2004). "Toyota Way: Management Principles from the World's Greatest Manufacturer". MacGraw-Hill Education.

Koskela, L. (1992). "Application of the New Production Philosophy to Construction", Stanford, CA: CIFE, Stanford.

Seranit. (2015). "Environmental Product Declaration: For Wall Tiles in accordance with EN15804 and ISO14025". <http://gryphon.environdec.com/data/files/6/11005/epd676en%20v1.1.pdf> (April 4, 2016)