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Productivity Improvement in a Peruvian Construction Company Using Lean Construction, Lean Six Sigma and TQM

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Abstract

Productivity in the construction sector has experienced a recent growth of 1% on average, which is very low, and this is reflected in economic losses for construction companies and, consequently, low productivity. The main problems that generate these losses are process delays due to unproductive time, construction material losses (referred to as waste) and the lack of total quality in the construction project. Therefore, this research seeks to eliminate or reduce as much as possible the low productivity in a company in the construction sector. For the situational analysis, diagnostic tools such as the Critical to Quality tree, the Ishikawa diagram and the 5 Whys were used. Likewise, the improvement tools applied were Lean Construction, Lean Six Sigma and Total Quality Management. From the results obtained, it was concluded that the improvement in non-productive time was 22%, concrete and steel material losses were mitigated by 5% and quality errors were reduced by 50%. The results were validated by means of a pilot test and the Arena simulator. An economic validation was also conducted using @Risk software, where an NPV of USD 8428, an IRR of 28.6% and a cost-benefit ratio of 2.1 were obtained.

Keywords
Lean Construction, Lean Six Sigma, TQM, Productivity and @Risk Simulator.

1. Introduction
Over the last two decades, labor productivity in the construction sector has grown by only 1% on average, which is very low compared to the 2.8% growth rate of the global economy. This reflects financial losses in the sector due to material losses or delays in the process (Hernandez and Oliveres 2018).

One of the factors that affect productivity is waste. This waste in construction affects workflow, which are activities with no added value (Castaño-Jimenez and Sanchez-Jurado 2021). Other studies have also identified waiting times, process delays, overproduction and unnecessary tasks as factors that reduce productivity (Utami et al. 2020). In addition, quality issues in the construction sector often lead to rework and corrective actions after project completion, resulting in resource losses.

The problems found lead us to study the case of a construction company in Peru, where these causes that generate low productivity are reflected and prevent the company from maximizing its profitability. The case study presents low productivity that requires a solution. The company faces unproductive times resulting from delays in certain activities and from waste occurring throughout the construction process. Identifying the specific activities where waste occurs are essential to reducing it. Furthermore, finishing defects and weak quality control lead to rework and additional costs, highlighting the need for continuous quality improvement.

Therefore, it was decided to develop a methodology based on improvement tools applicable to the problem, such as Lean Construction, Lean Six Sigma, and Total Quality Management. These tools address the causes of low productivity. This was demonstrated in a building renovation project in Denmark, where Lean Construction strategies improved productivity by 54% and enabled the project to be completed on time (Johansen et al. 2021). Similarly, after the implementation of TQM practices in a construction company in India, significant improvements in quality and productivity were achieved (Gupta and Khitoliya 2020). Lastly, Lean Six Sigma eliminates everything that does not add value to the final product and achieves a reliable workflow by reducing variability and solving root problems (Siregar et al. 2019).

The main contribution of this study is to show that integrating these three methodologies in a unified framework can improve the overall productivity of a construction company. The proposed approach provides an innovative methodological framework that can also be applied to other projects aimed at enhancing efficiency and ensuring continuous improvement.

In order to present the improvement proposal, this article is composed as follows: Introduction where the main problem of the sector is presented and the solution tools are proposed, the objectives, the literature review, which verifies the success cases related to the proposal presented, the proposed model, data collection, validation, results and discussion and finally the conclusion.

1.1 Objectives

The general objective is to improve productivity in the construction process using Lean Construction, Lean Six Sigma and Total Quality Management tools. On the other hand, the specific objectives are to reduce non-productive time, waste, and quality errors in the process and to validate that the proposed engineering tools are effective in solving the company's problems.

2. Literature Review

2.1 Lean Construction

It is an approach to construction project management and production based on the principles of the Lean system. The main objective of Lean construction is to reduce or eliminate activities that do not add value to the project.

The Lean Construction approach differs from traditional methods because it not only focuses on planning and controlling tasks but also seeks to understand construction as a production system. Under this paradigm, projects must be managed with an emphasis on reducing waste, improving the flow of information and materials and generating value for the client. (Koskela et al. 2018).

The Lean Construction philosophy has begun to be used in both European countries and Latin America, achieving good results in productivity, safety, quality, and significant reductions in project delivery times (Rodriguez-Diaz et al. 2019). Lean Construction has proven to be a tool that improves project performance. As a result, companies increased their productivity, according to 77% of those who used it. Significant benefits were also obtained through the use of Lean in the five fundamental aspects of the construction industry: reduction of work in processes, increased productivity, quality in production, reduction of cycles, and reduction of cycle times (Muñoz et al. 2021). The Lean Construction tool, called the Last Planner System, helps establish realistic and challenging plans that improve workload management and reduce project variability (Shehab et al. 2023).

One success story was a construction project in Mexico that applied Lean Construction, achieving a 26.56% improvement in time productivity. This result was obtained by identifying the causes of non-compliance and implementing corrective solutions. Many of these issues were related to material shortages, staff absenteeism and other similar factors. The identification of recurring problems improved the planning of material purchases and labor requirements, helping avoid schedule delays. As a result, the project was completed three weeks ahead of the planned delivery date (Perez et al. 2019).

2.2 Lean Six Sigma

It is a process improvement methodology that combines the principles and practices of Lean Manufacturing and Six Sigma. Lean Six Sigma seeks to leverage the efficiency of Lean to eliminate waste and optimize workflows and use the analytical capabilities of Six Sigma to ensure efficiency in results. This waste includes time lost in operations, unnecessary waiting times during production, rework, along with additional inefficiencies (Gazizulina and Muralidharan 2018). The DMAIC philosophy is used to develop this improvement tool. DMAIC is a structured problem-solving methodology that allows the root causes of problems to be identified and the appropriate solution to be implemented. It consists of five phases: Define, Measure, Analyze, Improve, and Control. During the Improve phase, Lean tools are applied to streamline and optimize processes (Sasikumar et al. 2023). The main benefits of its application include improved product quality, higher productivity and reduced process losses. These outcomes are reflected in greater customer satisfaction and business growth (Purba et al. 2021).

One success story includes a study of a residential building where the Six Sigma approach is used to measure and improve the on-site block construction process. One of the methodologies implemented was DMAIC, which resulted in a reduction in defects found. During the implementation of Six Sigma, considerable improvements were observed in the ongoing process, and it was noted that the same could be implemented in other processes involved in the construction of the building (Chadhauri and Wayal 2020).

Another success story was found in a company in China. The company achieved a significant reduction in construction time and waste generated after applying Six Sigma. According to the results, time and waste were reduced by 26.2% and 67%, respectively. This was achieved through process standardization, elimination of unnecessary activities, and better resource planning. The DMAIC cycle was applied to identify bottlenecks and improve workflow, and the main sources of waste were analyzed. Based on this, statistical controls and improvements in materials management were used to obtain the results (Vamsidhar 2019).

2.3 Total Quality Management

Total Quality Management (TQM) is a business management approach aimed at improving quality across the entire organization. It enables companies to achieve more effective process control, ensuring quality throughout all stages. In addition, it promotes greater performance evaluation and generates improvements in customers' perception of the company. Thanks to these benefits, TQM can be seen as an optimal quality management system for addressing the specific challenges of the construction industry (Budayan and Okudan 2022).

As a result of these improvements, non-conformities are reduced and the project's profit margin is increased (Riaz et al. 2023). On the other hand, by working under a quality system in all areas of the company, subsequent quality problems in a specific area can be avoided. In this research, Malcolm Baldrige's methodology was used for the analysis and development of Total Quality Management.

3. Methods

3.1 Basis

For the development of the proposed model, a literature review was conducted. Table 1 presents the studies that contributed to identifying the most suitable tools for the model. These tools were selected to address the three root causes of the company's main problem, low productivity.

Table 1. Comparative Matrix of The Proposal's Components

Scientific Articles/ Components	Improve time performance	Improve quality	Reduce waste
Abdul-Aziz, B. et.al. (2020)			Lean Six Sigma
Ali,A. and Tantekin,G. (2018)		TQM	
Bajjou, M and Chafi, A (2021)	Lean Construction		
Budayan, C. and Okudan, C. (2022)		TQM	
Chaudhari, S. and Wayal, A.(2020)			Six Sigma
Johansen, P et. Al (2021)	Last Planner System		
Klochkov, Y. et.al. (2019)			
Lyon, A.(2018)	Last Planner System		
Nowotarski,P. et.al. (2019)			Lean Six Sigma
Xang,X et al. (2024)		TQM	
Gamboa, P. and Laksono,S. (2021)			Lean Six Sigma
Perez, G. et. al. (2019)	Lean Construction		
Mcdermott,O. et al.(2023)			Lean Six Sigma
Uriz, L. et. al. (2019)			
PROPOSAL	Lean Construction	TQM	Lean Six Sigma

After identifying the improvement tools to be used, data were collected specifically for the selected ones. The key words for the search were Lean, Construction, Six Sigma and TQM. The repositories used for the search were Scopus, ProQuest and Web of Science. Exclusion criteria were also used according to the date of the research, taking into account that the research should be of recent years, that the articles should be in English or Spanish. Additionally, Boolean connectors were used to refine the search results. As a result, 250 sources were found at the beginning, and after a more detailed investigation by title, abstract and according to typology, 40 articles were finally found.

3.2 Proposed Model

Figure 1 shows the design of the proposed model for productivity improvement in a construction company. The model is innovative and covers solutions to all the main reasons for low productivity. Lean Construction was used by implementing the Last Planner System as a key tool to reduce non-productive time in the construction process, improve collaborative planning and optimize the execution of activities, thus increasing the efficiency of the project. Lean six sigma was also applied to reduce concrete and steel waste in the construction process, using the DMAIC methodology to identify when waste occurs and to support its reduction. Finally, Total Quality Management was used to prevent quality errors, improving efficiency and reducing rework costs. It also made it possible to promote continuous improvement throughout the company.

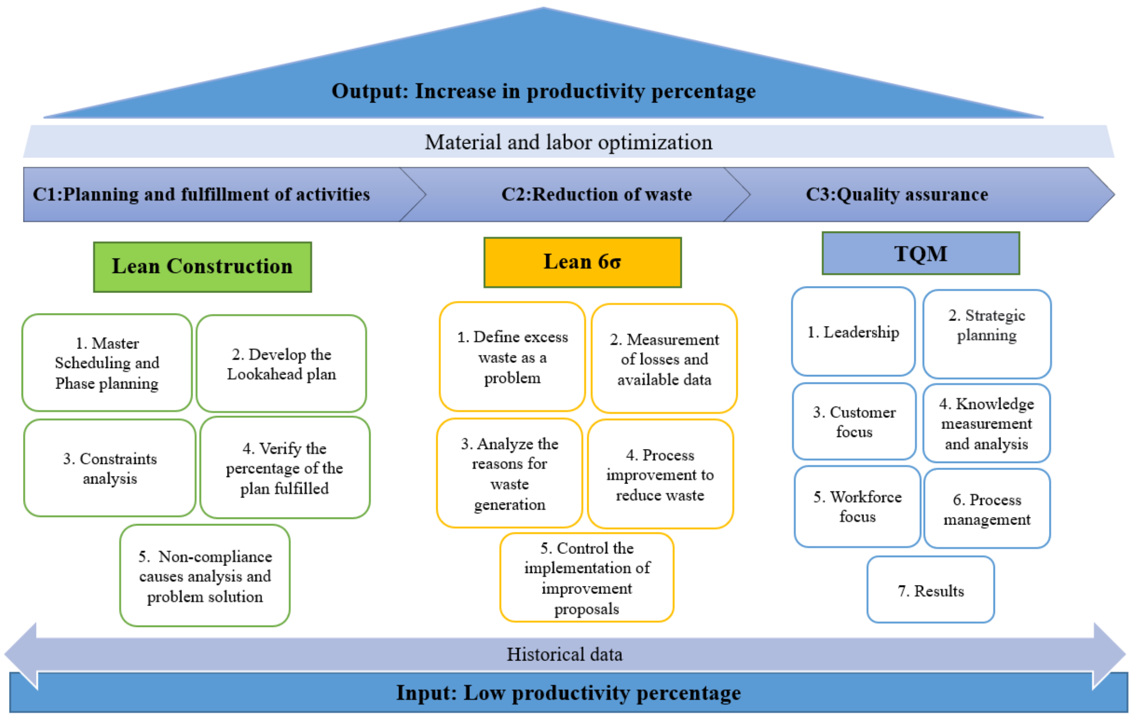

Figure 1. Proposed Improvement Model

3.3 Components

3.3.1 Component 1: Lean Construction

The first component involves planning and executing all scheduled activities. In implementing the Last Planner System, a Master Schedule and Phase Planning were first developed to define key objectives and project phases. This was followed by a Lookahead Plan to detail the upcoming activities for the construction project, which in this case was a building (Shehab et. al 2023). The project's status was first assessed, and planning began from that point. A three-week plan was developed based on the quantity takeoff of work to be completed each week. The next step was to identify constraints, meaning the activities that were either missing or required before starting those scheduled in the Lookahead Plan, Schedule compliance was then verified, and the causes of non- compliance were analyzed. Daily progress was recorded through quantity takeoffs to calculate the overall compliance percentage. Finally, the causes of non-compliance were classified and ranked by percentage to determine which should be addressed first and which had the greatest impact. Subsequently, corrective actions were implemented to prevent the recurrence of these issues in future projects.

3.3.2 Component 2: Lean Six Sigma

The second component consists of eliminating waste that occurs at certain stages of the construction process. First, the problem causing the waste is identified, then the percentage of waste is measured, and finally an analysis of the reasons for the waste is conducted (Castaño-Jimenez and Sanchez- Jurado 2021). In the improvement phase, the Lean tool to be used is an information-type Poka-Yoke. A manual is created for the correct use of materials in each activity to reduce the generation of waste. Finally, a control plan and a communication plan are created to ensure that the improvement is being implemented.

3.3.3 Component 3: Total Quality Management

The Malcom Baldrige model is used for quality assurance, applying the 7 criteria of the quality model. First the problems and quality objectives are defined, followed by the actions to be implemented within each criterion:

Leadership, Strategic Planning, Customer Focus, Knowledge Measurement and Analysis, Workforce Focus, Process Management and Results. Finally, the company's performance in the aforementioned criteria is monitored and its performance level is evaluated (Budayan and Okudan 2022). The objective is to ensure that the company achieves full compliance with the seven criteria, thereby working on the basis of a Total Quality Management culture.

4. Results and Discussion
4.1 Validation
4.1.1 Initial Diagnosis
During our investigation of this company, we discovered that the main problem was low productivity. Annually, they lose approximately USD 48,233 of their direct costs for three main reasons that generate low productivity. The first is non-productive time, which accounts for 45% of the company's low productivity. The second reason, which accounts for 35%, is excessive waste in the process due to poor inventory control and loss of raw materials in the process. Finally, the last reason is the occurrence of quality errors, which represents 20%. Figure 2 summarizes the initial diagnosis of the case study.

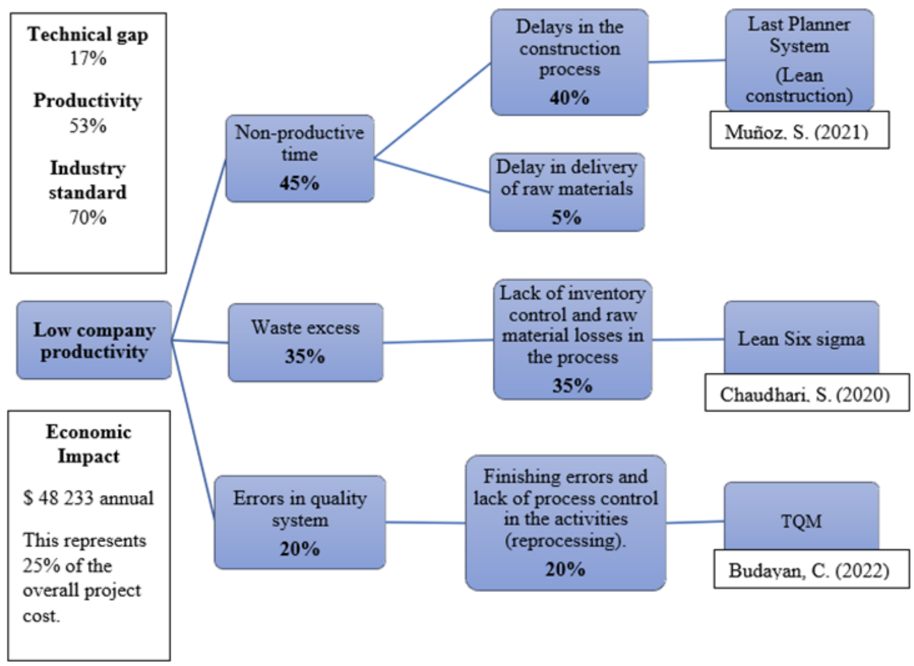

Figure 2. Problem Tree

4.1.2 Validation of the design and comparison with initial diagnosis
To validate the proposed model, the first step was to identify the root causes of the reasons mentioned in the initial diagnosis. For this purpose, several analysis tools were used, such as the 5 Whys, the Ishikawa diagram and Critical to Quality Tree. After the analysis, it was discovered that the root causes were delays in the construction process, failures in quality and controls that generated reprocesses, poor inventory control and raw material losses in the process. After identifying the causes, three tools were implemented to address them: Lean Construction for non-productive times, Lean Six Sigma for shrinkage problems, and TQM for quality failures. Once the tools were selected

and the objectives were established, the company's initial conditions were analyzed in order to proceed with the implementations.

4.1.3 Improvements

For this case study, the proposed Lean Construction and TQM solutions were pilot tested and a simulation was performed with Arena 16.20.00 to validate the use of Lean Six Sigma.

In the context of Lean Construction, the Last Planner System was used to eliminate non-productive time on site. First, it enabled collaborative planning from the beginning by involving the specialists responsible for each area in defining the activities to be performed and their sequence. This was accomplished through the Master Planning and Phase Scheduling (see Figure 1). The Lookahead plan was then executed to identify the activities scheduled for the following weeks and to assess their readiness. This tool also facilitated the detection of specific constraints that had to be resolved before causing delays in project activities. In addition, the system ensured that only tasks that were actually ready were scheduled so that each activity started with the necessary resources and conditions. Through the monitoring of the Percent Plan Completed (PPC) the level of planning reliability was measured and when a task was not completed the tool allowed to analyze the exact cause of non-compliance, which were reported in meetings with supervisors to take corrective actions. Thanks to this rigorous approach, the Last Planner System eliminated non-productive time related to delays and rework, achieving a continuous and efficient workflow.

For the application of Lean Six Sigma, the DMAIC methodology was employed, incorporating the Lean tool Poka-Yoke in the improvement phase. Regarding the first step it was determined that the materials generating the greatest losses were steel and concrete. Subsequently, the amount of waste produced for each material was measured. Then an Ishikawa diagram was developed to analyze the reasons behind the generation of these wastes.

In the Improvement phase, the process involving concrete and steel in the structural stage of the building was simulated, as these materials generate the highest levels of waste. To validate the results using Arena software version 16.20.00, the operators' activities were modeled considering execution times and quantities proportional to the real system. The simulation represented the processes involved in the placement of concrete and steel on site. A total of 100 replications were conducted to obtain the most representative results for applying the model to the company's operating process. The process was adapted to incorporate the application of Poka-Yoke in the corresponding activities, in order to minimize human error and reduce material waste (see Figure 3). The information-type Poka-Yoke consists of the inclusion of visual manuals and standardized procedures in critical stages of the construction process, such as concrete pouring in vertical and horizontal elements and steel measuring and cutting. In the simulation this type of preventive control is represented through blocks in Figure 3 (Use of Poka-Yoke 1, 2 and 3) configured with a low probability of error, instead of the higher values that would be used in the absence of the Poka-Yoke. This shapes the effect of having a clear guide for the operator. The entities were proportionally scaled to avoid exceeding the software's entity limit, resulting in 80 m3 for concrete and 101 batches for steel rods 9m each. The flow of entities follows the corresponding process until it bifurcates, depending on whether an error occurs. In the event of failure, it is assessed whether the material can be reused; if not, the corresponding loss is recorded. In this way, the model not only simulates the construction process but also quantifies the positive impact of applying this improvement tool during the execution stage.

For the final phase, a control plan was developed to ensure proper execution of each activity. In addition, a communication plan was created to establish an effective communication strategy that would support a successful implementation.

In the case of Total Quality Management, the first step involved identifying the types of quality errors present in the company, which were as follows: finishing defects, plumbing and electrical installation issues and design/ structural errors. This was followed by an internal evaluation of the company based on Malcolm Baldrige's seven criteria. The evaluation was conducted through a survey administered to company employees, designed to assess the company's condition at that point in time. The Malcolm Baldrige criteria showing deficiencies were identified, and the results also revealed weak management of nonconformities, insufficient standardization in technical processes, limited workforce involvement in continuous improvement and a lack of systematic error monitoring. Based on these findings, an improvement plan was developed. Through TQM, concrete actions were implemented to directly address the root causes of these problems. The introduction of controls, checklists and standard procedures led to a significant reduction in quality errors. Finally, a second evaluation was conducted to verify the effectiveness of TQM, confirming a notable decrease in quality errors. The improved processes were subsequently documented and integrated into the company's quality management system to ensure their continuity in future projects.

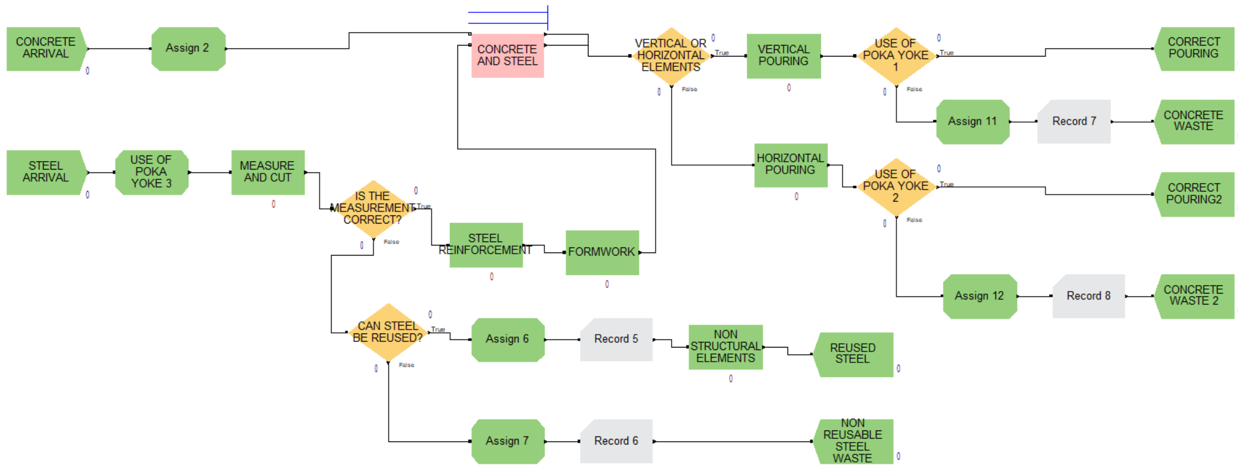

Figure 3. Arena Simulation of component 2

4.2 Graphical Results

The economic sensitivity analysis was done with @Risk software with the most influential variables of the project, the input variables used were the investment cost and the income for year 1, and the output variable applied was the Net Present Value (NPV).

The NPV of the project is 8428 USD. Figure 4 shows that the maximum and minimum values that NPV can take are positive, which is beneficial for the project. Finally, a tornado graph was made of the input variables classified according to how they affect the results. It was determined that revenue is the determining variable for the project and, therefore, is the variable with the highest sensitivity. Likewise, the investment cost variable causes the fluctuation of the NPV to fluctuate between the values of 8157 USD and 8595 USD. This variable is the least sensitive of the project. This economic analysis indicates that the application of these tools to improve productivity is financially sound and low risk, with a high probability of generating economic value even under adverse scenarios.

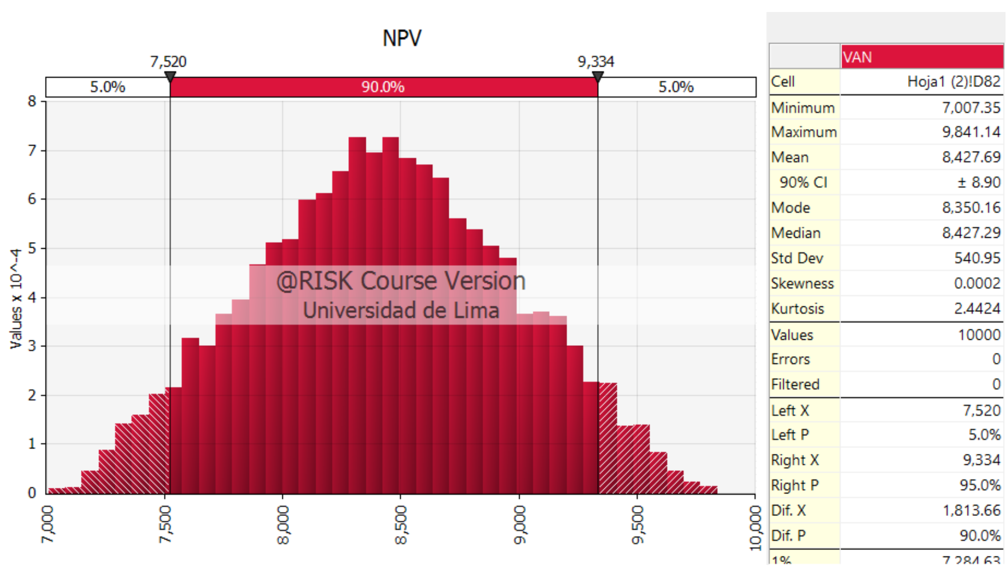

Figure 4. Validation of economic impact with @Risk

4.3 Numerical Results

Table 2 presents the indicators before and after the implementation of the tools. The indicator of incomplete activities, addressed through Lean construction and the indicator of quality defects, addressed through TQM, are field results, whereas the waste indicators, where Lean six sigma was applied, derives from simulation results.

In the study on time productivity improvement Perez et. al (2019) states that the application of Lean Construction and another tool for construction time optimization resulted in time savings of 26.56%. Based on this result in our project, we were able to reduce the number of uncompleted activities from 33% to 11% obtaining an improvement of 22%, which is a favorable result considering we applied only one tool to address non-productive time, while the referenced study used two. By implementing only Lean Construction our project achieved a significant improvement. This states that Lean construction is an optimal tool applicable for productivity improvement in a construction company and very favorable results can be obtained. The results obtained based on the indicators can be seen in Table 2.

With reference to a case study on waste reduction in the construction of an office building after applying the DMAIC and the respective improvements to its case, a global waste reduction was obtained from 6.15% to 3.39% that is to say that it was reduced by approximately 3% (Nowotarski et. al 2019), which is similar to the results of this project, since with respect to concrete it was reduced from 13% to 8% and with respect to steel from 11% to 6%. It can be seen that in this project a 5% reduction in waste was achieved, a higher percentage than the case of study. This may be due to a more complete and practical approach, since Lean Six Sigma with information-type Poka-Yoke was applied, which allowed not only to improve the process but also to intervene directly on the operational execution, helping to prevent errors from occurring or to detect them immediately. This study allowed not only to analyze the process but also to attack the errors directly and prevent them in real time, which other studies did not apply so directly.

By applying Total Quality Management in this project, quality errors were reduced by 50% (from 10% to 5%) while in a case study conducted in China where TQM was applied in a construction project with prefabricated components, a 27% reduction of errors and rework was achieved (Kang et. al 2024). Analyzing these results, the result of the study in China was performed in a prefabricated construction environment where processes are more controllable and repetitive, while this study was performed in a traditional construction environment where conditions are more variable, so this project faces real site conditions with time constraints and resistance to change. In this context the 50% reduction acquires a significant value for the construction company and achieving a clear improvement demonstrates not only the effectiveness of the approach but also its adaptability to more challenging environments and that with the continued application of this tool an error-free process can be achieved.

This study was conducted in a single construction company, which allowed for a carefully controlled implementation and yielded clear and measurable results on the effectiveness of the proposed framework. This approach provides a solid starting point for future research aimed at enriching the model in projects of greater diversity and scope. Moreover, the use of simulation to validate the model made it possible to assess its performance under safe conditions before implementation in real environments, saving time and resources and thereby strengthening the robustness of the results obtained. These features open up a wide potential for future research, such as replication across multiple companies and validation in simultaneous projects. Each new application will allow the approach to be refined and adapted, consolidating its potential for scalability and replication.

Table 2. Indicator Results

Proposal Model Measurements								
Problem	Baseline	Objective	Results	Cause	Indicator	Baseline	Objective	Results
Low productivity	53%	70%	79%	Non-productive time	Incomplete activities	33%	15%	11%
				High levels of waste	Concrete waste	13%	10%	8%
					Steel waste	11%	8%	6%
				Quality failures	Quality defects	10%	5%	5%

5. Conclusion

By applying Lean Construction, Lean Six Sigma and Total Quality Management it was possible to improve the productivity of the construction company to 79%, demonstrating the effectiveness of applying these tools directly to the root causes that can make a company go from having a low productivity to recover completely. In this way, by comparing the initial productivity baseline with the results obtained, productivity increased by 26%, surpassing expectations.

The implementation of Lean Construction allowed to eliminate non-productive time, ensuring a constant work flow, improving team coordination and resource optimization. This allowed 22% more activities to be carried out without any inconvenience, contributing to the increase of the company's total productivity.

The integration of Lean Six Sigma with Poka-Yoke on construction sites is a practical and highly effective solution to reduce material loss in the process in this case of steel and concrete. Lean Six Sigma provides a structured approach while Poka-Yoke significantly reduces the margin of error at critical stages. Together they increase productivity in a measurable and sustainable way.

The application of Total Quality Management allowed the company to reduce its quality errors by half. TQM is a strategic tool that enables construction companies to improve quality since the first time by ensuring more controlled processes and more consistent results.

These results provide clear evidence that the combined application of Lean Construction, Lean Six sigma and TQM enhances process performance and overall project productivity. This integrated framework constitutes a replicable and scalable model that can guide future studies and industry applications focused on operational excellence.

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