Building Vulnerability Reduction Through Lean Construction and BIM Methodologies to Boost Productivity and Effectiveness in the High Andean Area

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Abstract

Contemplating the problem generated by the low capacity of the construction sector in the houses located in the high Andean zone of Peru and the regulation of buildings, in this article we will seek to improve and optimize the execution processes in the highlands of Peru applying the methodologies of work of LEAN CONSTRUCTION-BIM METHODOLOGY for small and medium-sized companies, thus applying tools that generate value to the activities in the execution process, thus eliminating all types of material loss, seeking to reduce costs, increasing the collaboration of the work team and reducing the execution time of the work and the prevention of accidents, a study stage of the problem will be carried out, thus applying a small modeling with BIM where we will propose a minimum and adequate standard for constructions in the highlands of Peru and applying a standard of LOOK AHEAD for optimal progress of the work. It is known that in our country there are areas that are far from the main city, so they are excluded from everything. To talk about the types of construction forms and structures is to mention the precariousness that they have and where people are affected.

Keywords
Lean construction, BIM, Zona altoandina, Vulnerabilidad, Edificaciones

1. Introduction

Currently, work planning in Peru is a fact that should involve all groups of the various disciplines involved in construction. However, good organization is not always carried out; this is the case in places like Peru's High Andean zone, where there are few trained personnel to use new tools like lean construction and BIM. In this way, in the absence of planning, it is not possible to improve the effectiveness and productivity of the work. (Gomez 2021)

There will always be inconveniences and setbacks that prevent carrying out the activities that have been established. That is why possible fortuitous events must be foreseen and anticipated using appropriate tools such as programming software and work planning systems.

In the case of the high Andean areas, it is very common that there are delays in the work due to the lack of material, because the majority of them are brought from the capital and the climate of the high Andean areas is unpredictable This type of delay would be avoided if it were detected by a good system and planned for when each activity started. (Corahua 2017), as shown in Table 1.

Table 1. Comparison between production methods

	TRADITIONAL METHOD	LOSSLESS CONSTRUCTION
CONCEPT	Production is made up of a series of transformation activities that add value.	Production is made up of a flow (does not add value) and some transformations (add value).
PRODUCTION CONTROL	Targeted at the cost of activities	Directed to the time, cost and value of the flows.
IMPROVEMENT	Increased transformation efficiency through new technology	Elimination of activities that do not add value, increasing the efficiency of those that do add value through continuous improvements and new technology.

Source: Methodologies applied in construction

BIM is a trend that is expanding throughout the world, generating savings of between 15% and 25% in the global infrastructure market by 2025. 2018 EUBIN TASK GROUP

Building information modeling (BIM) is one of the most important and promising changes in the architecture, engineering, and construction (AEC) industry, as it represents a paradigm shift in the conception and management of projects, allowing the development of a detailed virtual model for the different phases of the life cycle of a project. By enhancing collaboration and harmony and achieving higher levels of efficiency, BIM enables integration into the AEC industry, which is often characterized by fragmentation. (DG Lee 2018)

Every day, the construction planning system in our country advances by leaps and bounds, which is why traditional planning methods have to be changed.

There are different types of construction work, so we should work on a general method and check if it is the same for all types.

Currently, the use of technology to develop different jobs, activities, and processes is more prevalent. BIM has emerged as a methodology that allows modeling in three dimensions and managing a project in order to optimize processes. As an economic justification, as described by EUBIM, if the use of BIM were to be extended across Europe, it would achieve a saving of 10% for the construction sector, generating an additional €130 billion. (Ostwald and Mojtahedi et. al. 2022)

In Peru, the implementation of the BIM methodology has ranged from minor to major. It began to be used to make three-dimensional models for sales presentations. Subsequently, the potential was seen, and the tours began in the planning stage for the preparation of the engineering and in the execution stage to understand the construction procedures based on how it would be finished. (Corahua & Lozano, 2017)

On the other hand, the lean construction methodology is older in the construction sector and focuses on project planning from the initial design stage to the final delivery stage. This methodology aims to maximize the resources used to build projects in order to produce the greatest possible value for users. (Rubio et. al. 2019)

Mentioning the above and perceiving the reality in the buildings and private investment, we see that there is a high level of poverty, particularly in the highlands of Peru, where the quality of life is low, where they do not have basic needs, and similarly, they do not have adequate planning and an economical and safe construction process. We will focus on presenting a pre-established BIM model for the executions, where we will take the criteria established by the A-010 standard and apply a defined standard applying the Lean Construction methodology. A predefined program will be used in the Look Ahead phase to seek a safe

execution, eliminate losses due to delays in inefficient internal processes, and improve the quality of buildings.

A second definition, also commonly accepted in the literature, is the one that defines Lean as the integrated socio-technical system whose main objective is the elimination of waste by reducing or minimizing internal variability, supplier variability, and customer variability. (Asier Latorre Uriz 2015).

2. Literature Review

BIM integrates all the agents involved in the process, such as engineers, architects, builders, owners, specialists, etc. This facilitates collaboration and communication between all parties since they work with a single information model based on real data.

In other words, Building Information Modeling (BIM) is currently considered the most innovative methodology in the entire construction sector. In essence, BIM provides an intelligent digital representation of buildings to support various activities throughout the life cycle of projects, generating a wide range of benefits for various aspects of the delivery process. Increasing inter-organizational and interdisciplinary collaboration in the architecture, engineering, and construction industries to promote productivity and quality in the design, construction, and maintenance stages of a building (Vilutiene 2019)

In addition, the BIM methodology is defined as a collaborative work methodology for the management of public investment information that makes use of an information model created by the parties involved, as shown in Figure 1.

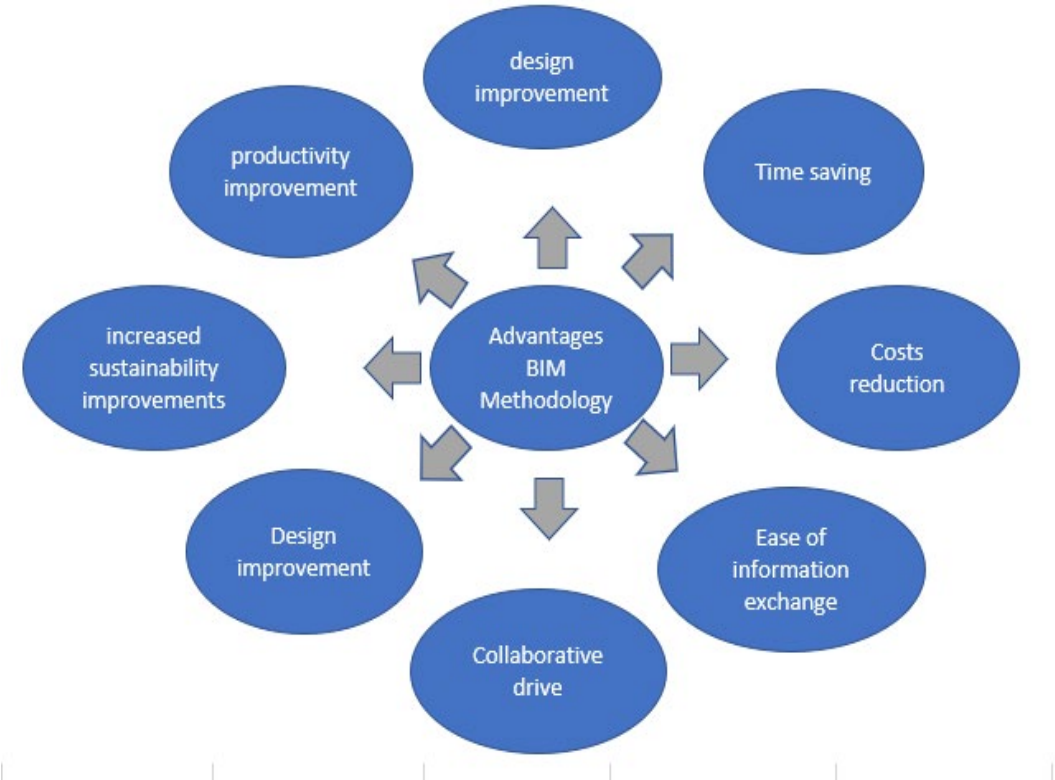

Figure 1. Advantages of the BIM methodology.

Source: Vera Galindo, Carmen University of Seville

On the other hand, lean construction is based on the management of construction processes following the principles of continuous improvement. covering the application of lean principles and tools to the complete

process of a project, from its conception to its execution and commissioning. providing various tools to achieve lossless production. These tools enable us to reduce the sector's high variability and view construction as a process flow.

The Lean philosophy seeks to eliminate everything that does not add value to the final product, in such a way that all activities that generate a cost for the company but do not add value to the product disappear or are minimized as much as possible. (Asier Latorre Uriz, 2015), as shown in figure 2.

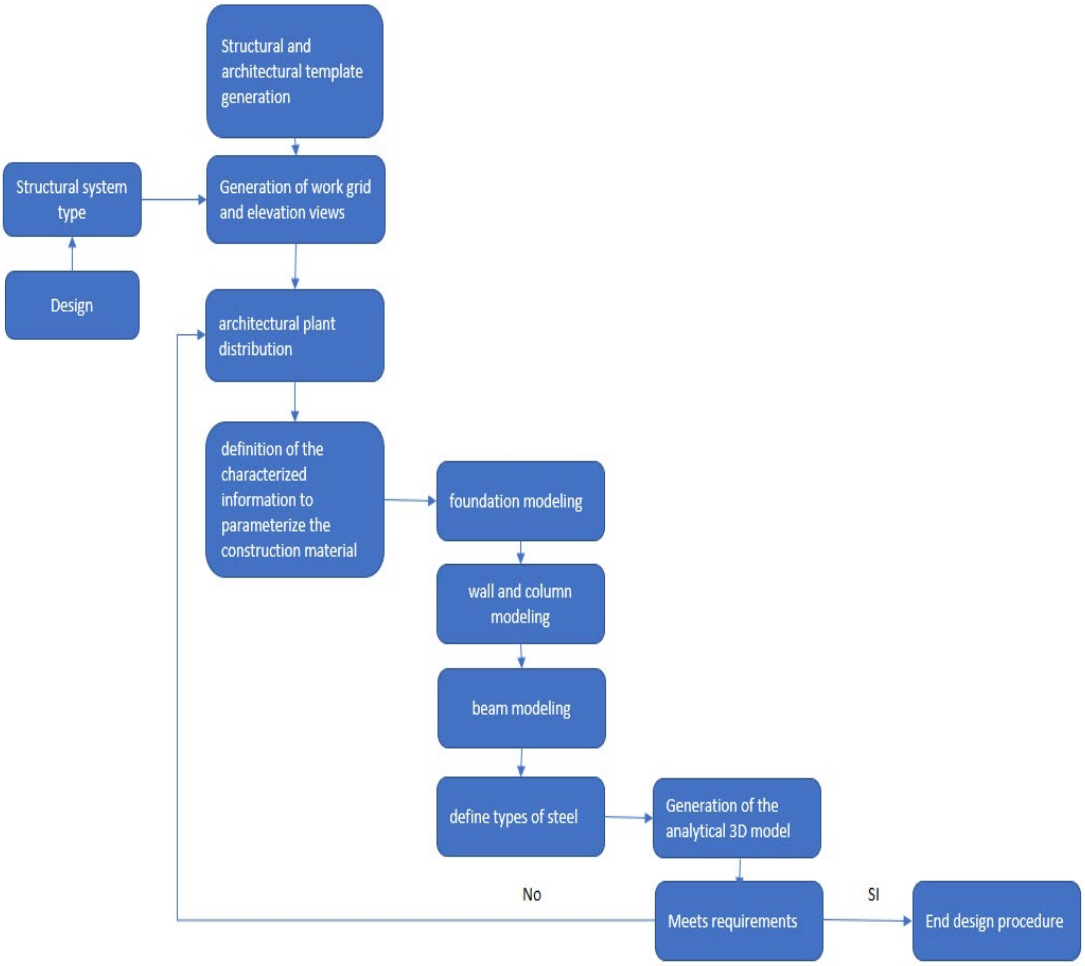

Figure 2. Production Lines

Source: self-made.

2.1. Lean Construction in Perú

Construction in our country did not have significant changes with globalization and the transformation of technology; it could still be considered handmade with minimal renewal of materials and little training of the actors, but on the other hand, it is one of the industries that dynamizes the country's economy by generating synergy in other industries. Using new approaches and methodologies, we seek to abandon craft construction in favor of series production; however, it is critical to understand that we must change our mindset and view the processes differently in order to do so. The same things, expecting different results. LEAN seeks to eliminate waste, reduce losses in the process, and add value to the product.

The construction sector is highly traditional, where the techniques used in execution and management have not varied much over time and are far from other industries such as the automobile industry or technology, which apply new methodologies for constant improvement, such as Lean, Kaizen, Pull, etc. In construction,

the fact that unique projects are generated in ever-changing contexts should not be an impediment to trying to implement execution and management techniques and methodologies that improve the final result of each project. (Calderon Rivera 2020)

2.2. BIM in Peru

The BIM Peru Plan is a policy measure proposed in the National Competitiveness and Productivity Plan promoted by the Ministry of Economy and Finance. This plan defines the national strategy for the progressive implementation of the adoption of BIM in the processes of the phases of the investment cycle developed by public entities and companies subject to the National System of Multiannual Programming and Investment Management, in an articulated and agreed-upon manner with the private sector and academia. The BIM Peru Plan establishes the objectives and actions so that BIM is implemented in investments, progressively, by all entities and public companies subject to the National System of Multi-Year Programming and Investment Management by the year 2030. The BIM Peru Plan seeks to guarantee proper execution of investments, improving their quality and efficiency during the investment cycle. (Ortiz Cruz 2018)

2.3. High Andean Zone

The high Andean zone in Peru is understood to be the Sierra region; it is the mountainous and highland region of the country made up of the middle and highlands of the Andes Mountain range. It extends throughout the country from north to south, and within the geography of Peru, it constitutes a traditional geographic region. It is bordered to the west by the Coast region and to the east by the Selva.To the north, it has continuity with the Inter-Andean Region of Ecuador and to the south with the Andean Region of Bolivia and Chile.

The Andean region is a geographical, biogeographical, and cultural concept. Orographically, it is the product of elevation and rock folding that originated during the Cretaceous, when the terrestrial crust of the Nazca plate began subduction under the South American plate, giving rise to an elevation that reaches 6768 meters above sea level in the snowy Huascarán and the formation of a volcanic mountain range in southern Peru. It is a biogeographic region with vegetation of intermediate density between the desert coast and the tropical forest, as well as a mountain climate that ranges from temperate to cold depending on altitude. Culturally, it is related to the high Andean culture of Peru, which is ethnically mostly quechua and Aymara, as shown in the figure 3.

Figure 3. Housing Model in the High Andean Zone.
Source: Andean

Lookahead, its main purpose is to control the workflow, understood as the coordination of design (plans), suppliers (materials and equipment), human resources, information, and prerequisites that are necessary for the crew to fulfill its work. (Pacheco Zuñiga 2016)

Peru is one of the countries with the greatest vulnerability to climate change due to our geographical location.

Alpaca communities in the high Andes are exposed to events such as earthquakes and low temperatures, which even led the Peruvian government to declare Puno in a state of emergency during the 2013 frost season. For this reason, they do not present safe conditions to be inhabited in this context.

This situation has generated various campaigns to improve housing and the health of the inhabitants; however, some of the interventions carried out are a repetition of foreign technologies that, in addition to not being compatible with the social, environmental, and/or cultural context, many times do not have a correct execution. (Gayoso Carranza 2016)

Identify activities

Let the towing plan dictate the next activities. Simply ask trading partners to identify activities that can be worked on over the next six to eight weeks. Record the activities in the advance plan.

This creates start and end dates for each activity. Evaluate the activities to determine constraints. Do not ignore this process. Each activity must have certain known information, materials, and labor available to begin. Every week, your team should have a forecast meeting.

This is the opportunity to review the constraint record and confirm that each constraint is being created by the responsible party. Spreadsheets, like activity sheets, are easily distributed and can be reviewed quickly.

3. Methods

At this stage, it is important to identify the different phases that the project will have, understanding that for each phase, what is known as "phase planning" must be carried out (Juan Felipe Pons, 2019), as shown in Figure 4.

We must make a guide on how we will apply lean construction and BIM.

3.1 Identify the area

-Location: high Andean area

-Method to apply, lean construction methodology, and BIM.

-The high Andean areas in Peru are Puno, Moquegua, Tacna, Cusco, and Arequipa.

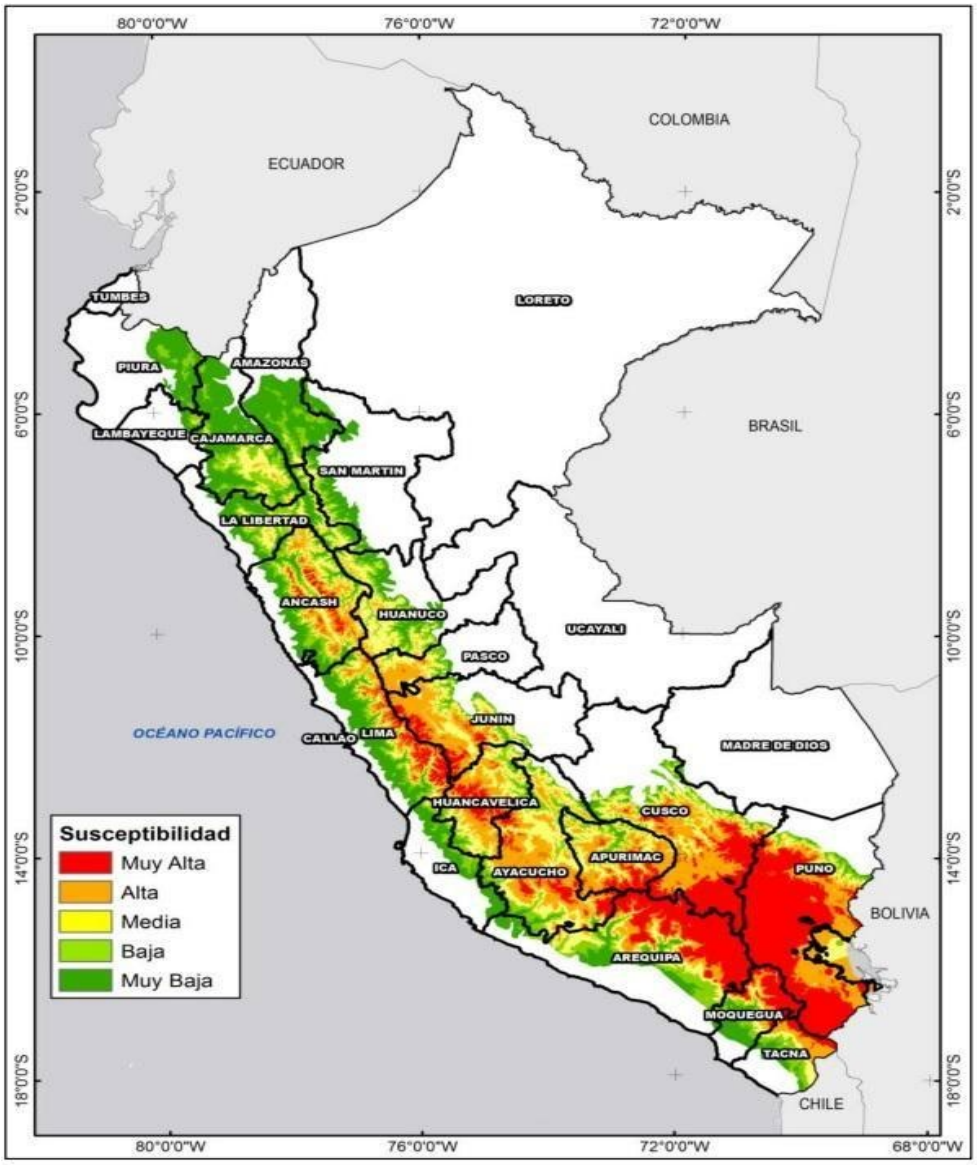

Figure 4. High Andean areas.
Source: SENAMHI

3.2 Apply the steps for the lean construction and BIM methodologies

According to Vaagen (2021), the following lean and BIM methodologies must be applied according to the following steps:

- Building information modeling.
- 5S: instructions on how to organize and maintain a workplace
- Just-in-time (JIT)
- First in, first out (FIFO)

The starting point of Lean philosophy is value. Value can only be defined by the final consumer, and it is only significant when it is expressed in terms of a specific product (a good or service, or both at the same time) that satisfies the consumer's needs at a specific price and at a specific time. Value is created by the organization, from the customer's point of view, which is why they exist.

The concept of client provided by James and Womack is qualified; the client for them is the one that defines the value, but only the final client. At present, the concept of the client goes further, and it is considered that the client can be both the external and internal clients of the company, as shown in figure 5 and 6.

3.2.1 Workflow and application sequence

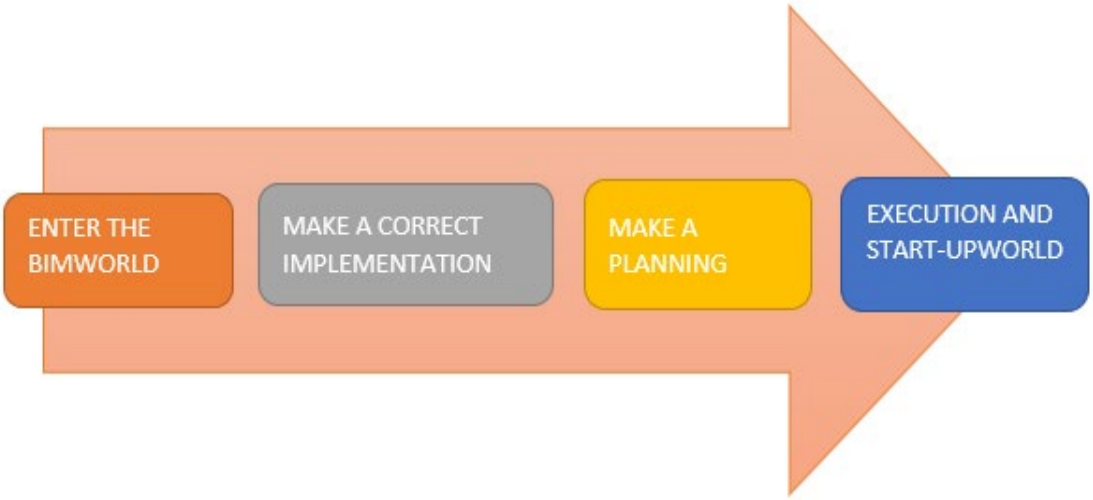

Figure 5. BIM model

Source: BIM methodology implementation plan

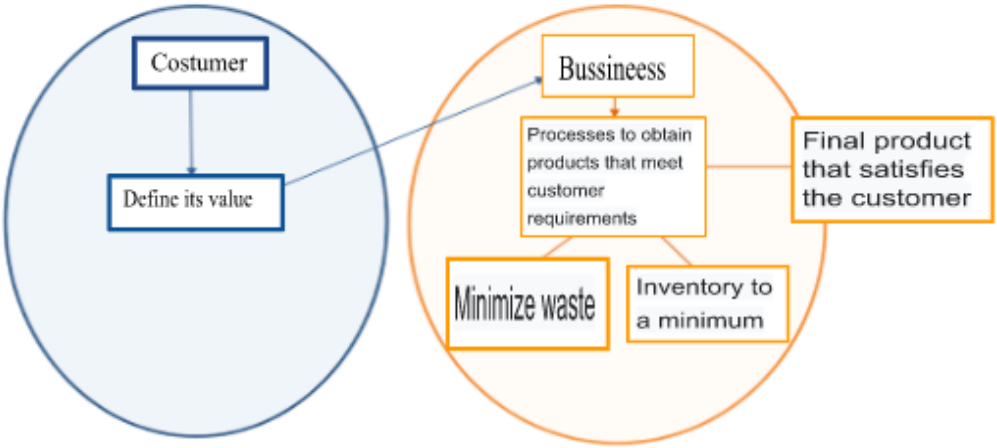

Figure 6. Lean Construction Model.

Source: Lean Construction Implementation

3.2.2 Identifying the area

Location: High Andean Zone, Puno, Moquegua, Tacna, Cusco, and Arequipa.

3.2.3 Applying lean construction and BIM methodology

Structural design

This stage begins with the architectural model, with which a structure as regular as possible is proposed, and, based on it, carries out the pre-dimensioning of the structural elements. With the structure already pre-dimensioned, the modeling is done in Revit. This is software where most of the project information is centralized since it allows interoperability with other software from different disciplines.

4. Results and Discussion

According to the investigation of the lean construction and BIM methodology, applied in a high Andean area, we can discern that there is an improvement in the productivity and quality of the construction, thus managing to optimize costs, as shown in the table 2.

Numerical Results

Table 2.
Comparative table of the budget, BIM method vs traditional method

BASIC INFORMATION	PROPOSAL BIM	PROPUESTA TRADICIONAL
CITY	CUSCO	
DISTRICT	SAN SEBASTIAN	
TYPE	EDIFICATION	
INFORMATION PROJECT		
AREA	120	120
HEIGHT (FLOORS)	2	2
ESTIMATED TIME FOR THE PRE-CONSTRUCTION STAGE (MONTHS)	1,5	2
ESTIMATED TIME FOR THE CONSTRUCTION STAGE (MONTHS)	0,5	4
ESTIMATED TIME FOR THE POST-CONSTRUCTION STAGE (MONTHS)	1	1
COST PER MODULE		
DIRECT COST	68,641,59	132,987,93
PRICE FOR SALE x M^2 OF THE LAND	78,000,00	78,000,01
INDIRECT COST		
GENERAL EXPENSES	8,230,99	15,958,55
UTILITIES	6,864,16	13,298,79
DESIGN COST AND LICENSES (REGARDING SALES)	1,372,83	2,659,76
PROJECT MANAGEMENT COST (REGARDING SALES)	3,432,08	6,649,40
UNFORESEEN COSTS (REGARDING SALES)	1,372,83	2,659,76
MODULE COST IN SOLES	167,920,48	252,214,19
TOTAL COST OF THE MODULE IN DOLLARS	51,667,84	77,604,37

Source: Ascue, Mamani, Mendoza, Mujica, Sotomayor (2018)

It can be observed that the direct cost through the BIM methodology represents 52% of the direct cost through the traditional methodology, which represents a savings of 50%, mainly due to the search for improvements in construction processes.

It can be improved using lean construction, as shown by the following productivity curve, which was prepared with data from a batch of a certain work and in which it was possible to verify that by applying the new methodologies, greater advantages are achieved, such as increased profits, decreased time, and reliability in execution terms.

Through research, it was tried to see how the necessary resources, which are labor, materials, and equipment, are managing to improve the cash flow estimate for the resources and thus avoid delays, which

generate better reliability in the programming. (De la Vega, Palomino, Guitierrez, Salcedo, 2018), as shown in Table 3.

Table 3. Reliability in the programming

PLATE FORMWORK	FEBRERO									
RUP BASE	26	27	28	29	30	31	32	33	34	35
DATOS	05-feb	06-feb	08-feb	09-feb	11-feb	14-feb	16-feb	18-feb	20-feb	21-feb
HH DIARY	25,75	34	55,5	23	7,75	16	23	28,5	66,5	26,5
DAILY ADVANCE	30	39,48	74,01	18,98	4,75	17,82	30	39,48	74,01	23,73
HH ACCUMULATED	1152,8	1186,8	1242,3	1265,3	1273	1289	1312	1340,5	1407	1433,5
CUMULATIVE PROGRESS	913,62	963,1	1027,1	1046,1	1050,8	1050,5	1068,7	1098,66	1138,14	1212,2
DAILY PRODUCTIVITY	0,86	0,86	0,75	1,21	1,63	0,9	0,77	0,72	0,9	1,12
STANDARD PRODUCTIVITY	1,68	1,68	1,68	1,68	1,68	1,68	1,68	1,68	1,68	1,68
ACCUMULATED PRODUCTIVITY	1,26	1,25	1,21	1,21	1,21	1,21	1,19	1,18	1,16	1,16

Source: *De La Vega, Palomino, Gutiérrez, Salcedo (2018)*

Graphical Results

PRODUCTIVITY CURVE

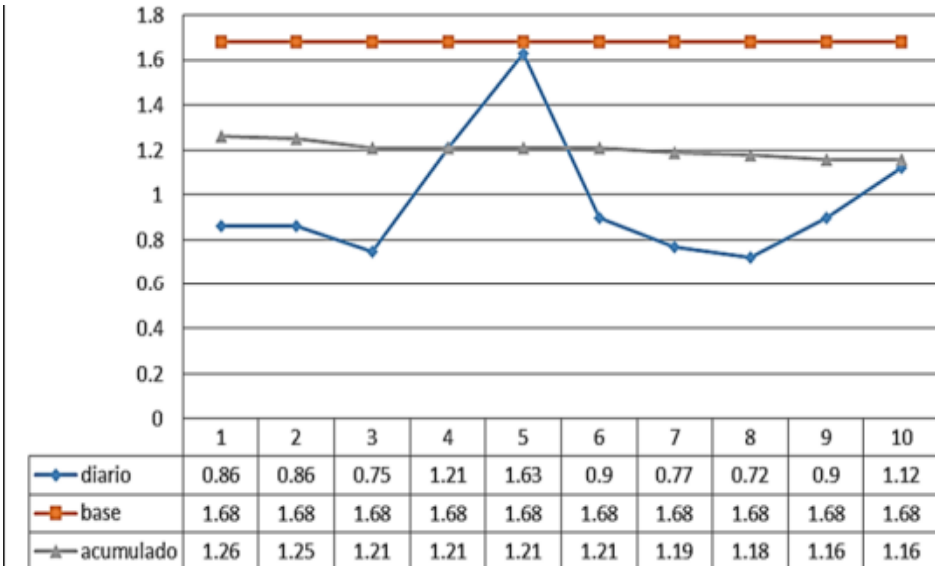

Figure 7. Productivity curve.

Source: De La Vega, Palomino, Gutiérrez Salcedo (2018)

5. Conclusion

- BIM and Lean construction methodologies are used to improve and perfect processes, specifically the construction process.
- With the data collected in the productivity curve, it can be determined based on profits that the daily value in period 5 is where the peak value of the graph is observed, which means that that is where a process is optimized.
- It is very important to be able to carry out different projects in which the continuous improvement of the day-to-day is prioritized in the different production processes. In addition, a good environment for total integration must be created.

- When applying the methodologies, the area must be taken into account, which in our case was the high Andean area, because each area of our country is different, whether due to climate, type of soil, materials, etc. For this reason, the process will vary depending on the area.
- After applying these methodologies, the most fundamental thing is being able to provide people with a quality, safe, and accessible product. As a result, the investigation found that using a methodology reduces production costs by 30%.

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