Reducing Waste on Construction Sites: A Focus on Timber Formwork System

Alberto Hugo Barriga Gallegos[1], Hector Raúl Machaca Condori[2], Virginia Gutiérrez Díaz[3], Dina Consuelo Navido Rodriguez[1], Yessica Noemi Machaca Fernandez[1], Osmar Cuentas Toledo[1*]

[1]Civil Engineering Research Group, Professional School of Civil Engineering, National University of Moquegua, Moquegua, Peru.
[2]Faculty of Geology and Metallurgical Engineering, Professional School of Geological Engineering, National University of the Altiplano, Puno, Peru.
[3]Master in Construction Management and Administration, Graduate School, National University of Engineering, Lima, Peru.
Email: ocuentast@unam.edu.pe.

The research verifies the waste generated in the construction works of buildings at the National University of the Altiplano in Puno - Peru. The objective is to identify the construction processes involved in developing material waste produced at work, evaluate the types of waste they create, and determine the percentage of waste generated, assessing the excess or tolerance within the limits expected of construction losses. The results indicate that in the evaluated projects, waste represents, on average, 28.87% of the total cost of the progress executed. Wood waste represents more than 30% of the total; even in a study sample, it exceeds 90% of the total waste generated. Likewise, the construction process of formwork and stripping of structural elements affects waste generation by more than 50% in all the samples evaluated. This brings the problem of an additional cost for the disposal of this material, which accumulates in the construction fields. It proposes an alternative that reduces waste, focusing mainly on waste resulting from the wooden formwork system.

Keywords: Waste, Framework, Timber, Construction Process, Wood, Wire.

1. Introduction

On the university campus of the National University of the Altiplano, located in the city of Puno (Peru), building construction projects are increasing. This increase inevitably generates high quantities of material waste from construction processes that still use traditional and old techniques commonly applied in the local environment.

The little development and poor implementation of new technologies collaborate to increase waste production in the construction sector. There needs to be a genuine interest in the sectors

involved in construction, especially the public sector, in looking for alternative solutions that allow them to reduce their waste emissions when building construction projects. Also, interest doesn't exist in where material waste will be deposited, how to stop or reduce and the damages it may cause.

In many cases, waste from construction works ends up in the environment, generating significant environmental alterations, contamination of soils and aquifers, and loss of potential resources. Despite the proposals for the management of construction waste once it is generated, it is also essential that they try to reduce their waste emission at the time of construction of buildings. Thus, the subsequent waste management will be more economically and environmentally viable [7].

The authorities in Peru have found themselves in a reckless need to implement a series of laws and regulations that govern the procedure both in the execution of the works and in all the processes involved. Involved in the stages before and after the completion of the project [5].

Despite the proposals for the management of construction waste once it is generated, it is also essential that at the time of constructing the building projects, they try to reduce their waste emission and, thus, the subsequent management of the waste be more economically and environmentally viable.

For this reason, it is essential to look for solutions for the current situation. Although previous work was carried out to manage waste better, more is needed to reduce the amount of waste generated during their execution. To do this, it is necessary to determine which factors generate this waste and propose alternatives that allow better control in the execution of the works and thus reduce the emission of waste.

This article has been prepared to propose alternative solutions that construction projects can apply to the waste generated. The most effective strategies are the prevention and reduction of waste. These strategies, if implemented, can bring about a significant positive change in the construction industry, especially during the design phases of the works [4].

The present investigation pretends to identify the material waste that is generated in high quantities, as well as the construction processes by which they are produced and the damages they bring with them, to propose then more appropriate alternatives that allow developing strategies in the future so that in the works executed by direct administration become more involved in the search to improve their construction processes, implement new technologies and thus be by the regulations to comply with them and develop sustainable construction with society and the environment.

All the information collected will allow us to identify the construction processes that generate the most significant amount of material waste in the construction phase and, determine the negative consequences caused by these amounts of material waste, then propose an alternative to reduce material waste in the construction phase, the construction phase of buildings in the University campus.

2. Materials and Methods

2.1. Study Area

The objective of this research was to collect data according to the stage of construction in which the evaluated projects were, where the construction processes on which great attention was chosen, and in turn, the waste derived from these processes was determined, which are the ones that were measured. The quantities were obtained to determine which processes are most involved in generating material waste.

2.2. Methodology

Instruments were needed to evaluate the amount of materials considered waste and to allow their verification once found in the construction work field. Among the instruments used, we have the tape measure to determine the length of waste, such as steel or PVC, measured in meters.

Also, it was used to measure the dimensions of those wastes that are quantified in area units, such as ceramic or glass finishes, and those that are quantified in volume units, such as wood, nails, wires, and sawdust. Or clearance material or pieces.

In the same way, the support of photographs was necessary to show the amounts of waste found. It is important to visualize how waste is found on-site during the construction phase and what actions must be taken so that it is not found in the same places later.

Finally, sheets were used, which were prepared to collect data in the different construction works selected as a sample, as well as for subsequent calculation of the amount of waste found in each of them. Information is included on the location areas of waste found, the measurements taken and the partial and total calculation of the determined quantity according to the type of waste material.

In total, three (03) different models of sheets were used: A sheet for recording waste of found material, a sheet for quantifying waste of found material, and a sheet that included both and was used for specific materials and with a simple calculation.

The calculation of each waste material was carried out using simple volume calculation methods. It was converted to its equivalence in the unit of each material used for the unit cost of the budget of the evaluated projects.

For example, in the case of wooden formworks, a stacking coefficient proposed by Vázquez et al. (2016) allows for obtaining a volume that is more approximate to the actual amount of wasted wood that was determined in the work in the construction phase. In the case of nails and wires, their specific weight was verified with measurements made in the laboratory, both loose and compact [6].

The controls and measurements on material waste were carried out for three (03) months in each project selected as a sample.

For example, to calculate the amounts of wood waste, area measurements in square meters (m^2) were used in the case of non-reusable formwork, and volume in cubic meters (m^3) for non-reusable wood scraps and logs, which were obtained through data collected in the field (Dimensions of waste found) and formulas that allow calculating the estimated volume of

unusable wood found.

3. Results and Discussion

We can obtain the approximate cost generated by each type of wasted material in the evaluated projects and the total cost of waste produced to get the percentage of incidence each material represents concerning the total found.

This will allow us to identify which materials represent the majority of waste generated and on which special attention will be paid to evaluate a possible reduction alternative.

Likewise, based on these percentages, we can calculate how much the construction processes carried out in the evaluated construction projects affect according to the origin of each aspect of waste and thus identify those that generate the most waste.

Summary graphs of the waste found in each evaluated project are presented, ordering them from highest to lowest percentage, where high waste is considered to be those that exceed 5% of the total cost of waste found during the verification period and waste in a smaller amount than those that do not exceed this limit, which are grouped into a single item.

Concerning the total waste found, for all the projects evaluated, the most significant percentage of waste costs comes from the wood and wires used for the formwork, as seen as seen in Figure 1, Figure 2 and Figure 3 obtained for each project:

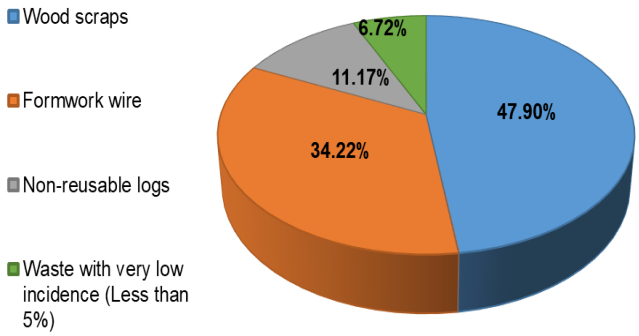

Figure 1. Percentages of waste costs found in Project 1.

With the results obtained, the average cost generated by each waste found in Project 1 was calculated, which is:

$\bar{x}$ = (∑ Costs) / (Amount of waste) = 403029.37/17 = 23707.61 PEN

The fashion in Project 1 is wood scraps, as they appear most frequently in the amount of waste found, with 47.90% of the total waste cost.

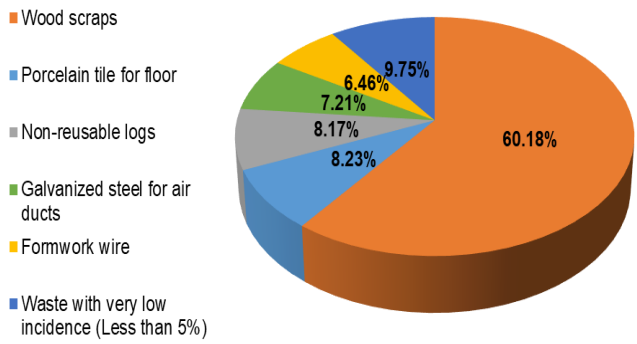

Figure 2. Percentages of waste costs found in Project 2.

With the results obtained, the average cost generated by each waste found in Project 2 was calculated, which is

$\bar{x}$ = (∑ Costs) / (Amount of waste) = 143445.75/18 = 7969.21 PEN

The fashion in Project 2 is wood scraps, as they appear most frequently in the amount of waste found, with 60.18% of the total waste cost.

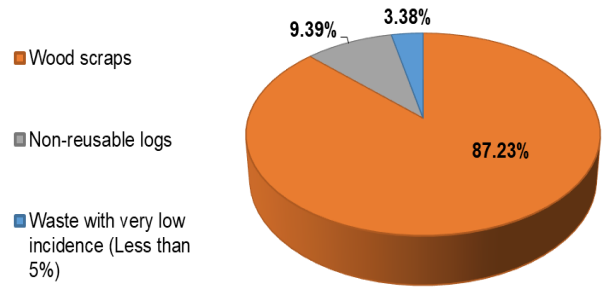

Figure 3. Percentages of waste costs found in Project 3.

With the results obtained, the average cost generated by each waste found in Project 3 was calculated, which is:

$\bar{x}$ = (∑ Costs) / (Amount of waste) = 101646.21/20 = 5082.31 PEN

The fashion in Project 3 is wood scraps, as they appear most frequently in the amount of waste found, with 87.23% of the total waste cost.

Project 3 still kept the waste wood on the construction site because it could not be removed since the costs of eliminating waste material generated on the job were not planned, as is the case of wood that can no longer be reused.

These percentages show us that most of the waste generated in the works in the construction phase in the University City comes from the wood used for formwork, both in scraps and in other aspects found.

Likewise, based on the percentages obtained for each waste, the incidence of the construction processes from which these found wastes were derived was determined. The results are shown in Figure 1, Figure 2 and Figure 3 obtained for each project:

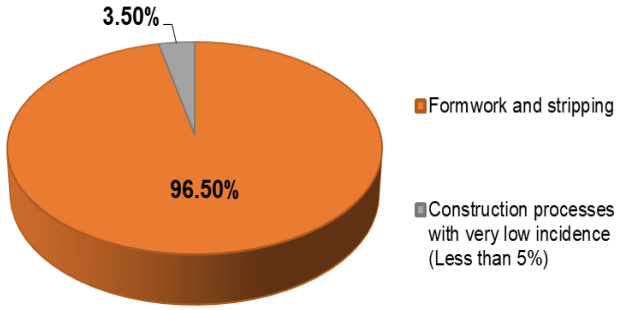

Figure 4. Percentage of incidence of construction processes project 1.

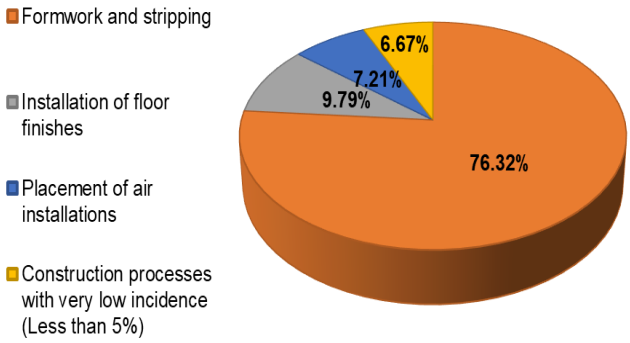

Figure 5. Percentage of incidence of construction processes project 2.

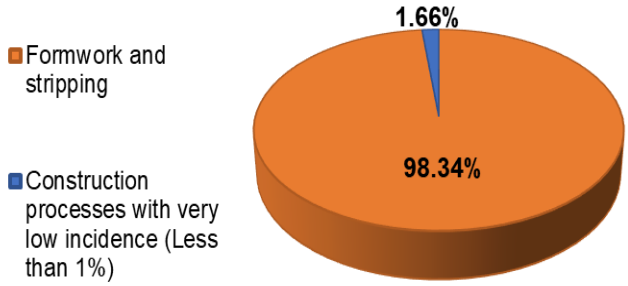

Figure 6. Percentage of incidence of construction processes project 3.

In all the projects evaluated, an evident influence can be seen in the construction processes of formwork and stripping of structural elements as the primary process that generates waste of

construction materials on the university campus, exceeding 50% of the total waste. Therefore, We must pay close attention to the possibility of establishing an alternative to reduce waste based on this construction process.

According to the results obtained, the most significant amount of waste generated in the works in the construction phase in the University City is mostly from wood. The percentages obtained are compared with those of other authors, such as Pinto (1989), which are shown in the following table, and it reflects that the percentages obtained are of high incidence, so it is essential to focus on the search for the reduction of these types of waste.

One of the construction processes that most affect the generation of material waste is the formwork and stripping of wood, which represents the highest percentage. This is because this process produces waste wood, nails, and steel wires that become unusable during the use of the formwork. The Table 1 and Table 2 shows the incidence percentages of each construction process evaluated in this research.

Table 1. Comparison of material waste percentages of the present investigation with those of Pinto (1989).

Material	Waste, according to Pinto (1989), (%)	Waste found Project 1 (%)	Waste found Project 2 (%)	Waste found Project 3 (%)
Wood in general	47.5	61.3	69.8	97.6
Steel CA 50/60	26.0	35.6	9.2	1.2
Ceramic (floor)	7.5	-	9.8	0.1

Table 2. Percentage of incidence of construction processes in the generation of waste at UNA-Puno.

Constructive process	Project 1	Project 2	Project 3
Formwork and stripping	96.50%	76.32%	98.34%
Placement of air installations	-	7.21%	-
Installation of floor and wall finishes	-	9.79%	0.32%
Placing glass for finishes	-	1.99%	-
Placement of reinforcing steel	0.45%	2.69%	0.55%
Ceiling placement	-	0.98%	-

Hauling of surplus material	1.85%	0.18%	0.62%
Assembling masonry walls	0.31%	0.49%	0.11%
Laying of lightened slabs	0.76%	0.03%	0.06%
Installation of pipes	0.13%	0.30%	-
Exterior wall cladding	-	-	0.01%

As can be seen, all the percentages of wood waste in the Samples studied exceed that obtained by Pinto (1989). However, all the percentages are still relatively higher than the usual expectation of losses that the same author proposes.

In the case of steel, the percentage in sample 1 exceeds that of Pinto (1989), but not in the other samples. It is precisely the wire that increases the rate of steel waste in this project. The different percentages of samples 2 and 3 are insignificant because they do not exceed the percentage of the usual expectation of losses.

Finally, the percentage of ceramics in Project 1 was not obtained because this waste did not occur at the project stage. The value obtained from Project 2 is striking since it exceeds that of Pinto (1989), although it does not exceed the percentage of the usual expectation of losses. The rate of sample 3 is not significant since it does not exceed either of the two percentages.

These results reflect that wood is one of the wastes produced with the most significant incidence in a construction project, which is worrying because it is a highly polluting material.

Next, the values obtained in the present investigation were compared with those of research closer to our local situation, such as that carried out by Chávez Cabrera, realized in 2016 [14].

It can be seen in the Table 3 that the percentages of wood waste exceed those obtained by Chávez (2016), but not those of brick, which are low compared to those obtained by the same author. All percentages of wood exceed the usual expectation of losses proposed by Pinto (1989), thus confirming the high incidence of timber in construction waste.

Table 3. Comparison of material waste percentages of the present study with those of Chávez, realized in 2016 [14].

Material	Waste, according to Chávez (2016) (%)	Waste found Project 1 (%)	Waste found Project 2 (%)	Waste found Project 3 (%)
Wood	21.00	61.30	69.82	97.64
Brick	1.95	1.07	0.49	0.15

According to all the calculations carried out with the data obtained during the verification period, it can be stated that the formwork and stripping of structural elements is the construction process that mainly affects the generation of waste in the construction projects executed on the University Campus.

It can be seen in the following Table 4, which orders each construction process according to

the average percentage of incidence that it produces in general for all the projects evaluated and the percentages obtained in each project. The established order is from highest to lowest incidence since the reduction proposal is based on the construction process that significantly impacts waste generation.

Table 4. Average percentage of incidence of construction processes in the generation of waste at UNA-Puno.

Constructive process	Project 1	Project 2	Project 3	Average
Formwork and stripping	96.50%	76.32%	98.34%	90.39%
Placement of air installations	-	7.21%	-	7.21%
Installation of floor and wall finishes	-	9.79%	0.32%	5.05%
Placing glass for finishes	-	1.99%	-	1.99%
Placement of reinforcing steel	0.45%	2.69%	0.55%	1.23%
Ceiling placement	-	0.98%	-	0.98%
Hauling of surplus material	1.85%	0.18%	0.62%	0.88%
Assembly of masonry walls	0.31%	0.49%	0.11%	0.30%
Laying of lightened slabs	0.76%	0.03%	0.06%	0.28%
Installation of pipes	0.13%	0.30%	-	0.22%
Exterior wall cladding	-	-	0.01%	0.01%

Based on this, we can propose that the best alternative to reduce waste emissions in UNA-Puno projects would be formwork made from metal, which has significant advantages over wood, such as the possibility of reusing and putting them into work immediately, without the need to elaborate. Likewise, it has disadvantages such as its high cost and installation on-site by specialized staff.

Regarding the advantages that a metal formwork can bring compared to a wooden one, Paz-Jáuregui (2014) mentions that among the significant problems that a wooden formwork presents, it can be indicated that the surface finish is not optimal and on the other hand, reuse is minimal because when the formwork is dismantled, there is always damage or breakage in the wood. The author adds that, on the other hand, steel formwork can be removed and cleaned very quickly, and reuse is almost unlimited.

There are several metal formwork manufacturers worldwide that have developed formwork that adapts to various sizes of columns or beams. Still, manufacturing a product locally that meets the requirements of each project is always much more convenient for a specific project [21].

The following Table 5 shows the characteristics that the workforce requires for formwork and the training that is needed according to the type of formwork system intended to be used [17].

Table 5. Comparison of labour training regarding the formwork system to be used

Labour Characteristics	Training Level		Justification	
	wooden formwork	Metal formwork	Wooden formwork	Metal formwork
Skilled labour	high	Low	Master carpenters	Workers
Training needs	high	Half	For levelling and repair	Assembly training
Number of people needed	Half	Half	2	2

Source: Oribe (2014)

Based on these data, we can say that using metal formwork is more advantageous than wooden formwork in terms of labour, in addition to the significant reduction in the emission of waste on-site.

4. Conclusion

Most of the amount of material waste generated during the construction stage in the samples studied comes from the construction process related to the formwork and stripping of structural elements, which represents an average of 90.39% obtained in the three samples evaluated, which makes it the construction process with a very high incidence in the generation of material waste in the University City.

The construction processes related to reinforced concrete structures generate the most significant amount of material waste, as is the case of formwork and stripping, which represent 96.50% in Sample 1, 76.32% in Sample 2 and 98.34% in Sample 3.

The principal reduction proposal suggested to reduce waste of construction materials in the university city is focused on the construction process of the formwork, so the use of metal formwork is recommended since they have a more significant number of uses than the one that the of wood, favouring the execution of construction work in time and cost.

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