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Proposal of a model for the quantification of construction waste costs in the planning stage of construction projects

Propuesta de un modelo para la cuantificación de costos de residuos de la construcción en la etapa de planificación de proyectos de construcción

Gonzalo Garcés (*), Antonio Molina (**)

ABSTRACT

The construction industry and the production of inputs in this sector are the activities that show the highest rates of consumption of materials and raw materials worldwide. This research proposes a methodology that incorporates the estimation and cost associated with the waste generated in construction, incorporating the "Loss Factor" to the Unit Cost Analysis (UCA) that is associated with the cost of loss of a particular material. In addition, it is proposed to incorporate the typification of the "Ábaco-Chile" of the waste generated by each material defined in the UCA. On the other hand, a survey is carried out among 71 construction professionals, for them to estimate, according to their experience and criteria, the loss factor (%) associated with the cost of the most incident materials in the generation of waste in the construction. Based on the results of the survey, the probabilistic distribution that best fits the materials is determined, through the Crystal Ball software, determining the most probable loss factor (%), which would be the most recommended in case of not knowing how to estimate the loss factor. Proper waste typification and reliable estimation of the cost of construction waste before the commencement of construction activities will help decision-makers to better understand the cost implication of waste generation and improve their decision-making in developing the appropriate strategy that can mitigate construction waste generation.

Keywords: waste; construction; estimation; costs; planning.

RESUMEN

La industria de la construcción y la producción de insumos en este sector son las actividades que presentan las mayores tasas de consumo de materiales y materias primas a nivel mundial. Esta investigación propone una metodología que incorpora la estimación y costos asociados a los residuos generados en la construcción, incorporando el "Factor de Pérdida" al Análisis de Costo Unitario (ACU) que está asociado al costo de pérdida de un determinado material. Además, se propone incorporar la tipificación del "Ábaco-Chile" de los residuos generados por cada material definido en el ACU. Por otro lado, se realiza una encuesta a 71 profesionales de la construcción, para que estimen, según su experiencia y criterio, el factor de pérdida (%) asociado al coste de los materiales más incidentes en la generación de residuos en la construcción. En base a los resultados de la encuesta se determina la distribución probabilística que mejor se ajusta a los materiales, a través del software Crystal Ball, determinando el factor de pérdida más probable (%), que sería el más recomendable en caso de no saber cómo estimar el factor de pérdida. La tipificación adecuada de los desechos y la estimación confiable del costo de los desechos de la construcción antes del comienzo de las actividades de construcción ayudarán a los tomadores de decisiones a comprender mejor la implicación del costo de la generación de desechos y mejorar la toma de decisiones en el desarrollo de la estrategia adecuada que pueda mitigar la generación de residuos de la construcción.

Palabras clave*: residuos; construcción; estimación; costos; planificación.*

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1. INTRODUCTION

The construction industry and the production of inputs in this sector are the activities that show the highest consumption rates of materials and raw materials worldwide (1-3). The main inputs used and extracted from nature for the construction of buildings and infrastructure can be aggregates, copper, asphalt, cement, plastics, iron, aluminum, wood, plaster and bricks, of which a high percentage is discarded during the construction stage and also become waste when damaged by mishandling, or by demolition, or by weather, or when affected by natural disasters such as earthquakes and tsunami, among other reasons buildings (4). The term construction and demolition waste (CDW) is generally used to refer to solid waste generated in the construction industry, more specifically, the term is defined as waste arising from construction, renovation and demolition activities, including land excavation or formation, civil and building construction, site clearance, demolition activities, road works and building renovation (4, 5). Therefore, it is necessary not only to quantify the amount of waste in construction, but also to quantify and estimate the associated costs (4, 5). In addition, makes it possible to quantify the project's financing needs, considering the most appropriate mechanisms to successfully materialize the project (6).

In addition, it is not only necessary to quantify and estimate the costs of waste, but also to correctly classify and typify the waste generated in construction, since if the actors in the production or waste process know with certainty the origin of their waste, the raw materials used, the production processes, and know the current regulations and a correct classification and typification, then the waste identification process will be considerably more effective (7, 8). Knowing, for example, whether the waste is hazardous or not, will help to decide the most appropriate type of treatment for the identified waste, thus helping to prevent harm to people and the environment (9).

The present research proposes a methodology that incorporates the estimation and cost associated with the waste generated in construction, incorporating a new column called "Loss Factor" to the Unit Cost Analysis (UCA) which is associated with the cost per loss of a particular material, being a value, which can be represented in quantity or in percentage, in which to facilitate its understanding it is defined as a percentage, this value will be defined by the construction company or the professional in charge of the cost estimation. In addition, the proposed methodology incorporates the "Ábaco-Chile" typification of the waste generated by each material defined in the Unit Cost Analysis (UCA).

Therefore, proper waste typification and reliable estimation of the cost of construction waste before the commencement of construction activities will help decision-makers to better understand the cost implication of waste generation and improve their decision-making in developing the appropriate strategy that can mitigate waste.

2. BIBLIOGRAPHIC REVIEW

The construction industry is one of the most significant in the consumption of raw materials (1, 10). The International Resource Panel (IRP) report on "Priority products and materials" mentions the influence of different economic activities on the use of natural resources and waste generation (11). Figure 1 shows the evolution of the extraction of materials based on the extraction of four categories of raw materials: construction minerals, metals and industrial minerals, fossil fuels and biomass.

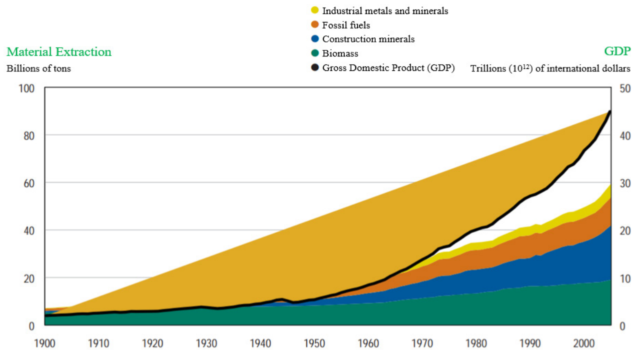

Figure 1. Extraction of materials, in billions of tons, 1900-2005. Source: Krausmann et al. (1).

The twentieth century was a time of progress for human civilization, due to technological progress and great demographic and economic growth. The annual extraction of minerals grew by a factor of 27, construction materials by 34, fossil fuels by 12 and biomass by 3.6 (1, 11). In total, material extraction increased by a factor of about eight, while GDP increased by a factor of 23. This increase in material consumption was not evenly distributed and had profound impacts on the environment.

2.1. Definition of waste

Waste is generated as a result of a linear production and consumption model, which is based on: extracting, producing, consuming and disposing to satisfy human needs (transportation, food, clothing, housing, communication, etc.) (3, 12). To better understand this model, it is possible to quantify and analyze the flow of materials in the economy (3). In this sense, according to European Council and Osmani (13, 14), waste is understood as any substance or object that the holder discards or intends or must discard, where this definition applies to all waste, regardless of whether it is destined for disposal or recovery operations.

Koskela (15) argues that waste adds cost, but does not add value. Similarly, Formoso et al. (16) classifies waste as "unavoidable", where the costs to reduce it are higher than the economy produced, and "avoidable" when the investment needed to manage the waste produced is higher than the costs to prevent or reduce it. Therefore, the concept of waste should be considered in terms of activities that directly or indirectly increase costs but do not add value to the project.

2.2. Construction and Demolition Waste (CDW)

The term construction and demolition waste (CDW) is generally used to refer to solid waste that arises from construction, renovation and demolition activities, including land excavation or formation, civil and building construction, site clearance, demolition activities, road works and building renovation (4, 5, 17, 18).

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Numerous quantification methodologies for CDW generation have been proposed in the literature (19-22). However, there is still no systematic review that analyzes these methodologies and discusses their scope of application in the planning stage of the construction project. Decision-makers must have a clear idea of the characteristics and implementation limitations of alternative quantification methodologies before choosing a suitable one (23, 24). Therefore, a systematic review is important to bridge the gap.

2.3. Chile's construction industry

There is an estimate regarding the generation of CDW waste originating in buildings (houses and buildings), where, based on official data from construction permits and waste generation models, there are around 7 million tons of CDW per year, only from buildings. This result should include the waste generated by the demolition of buildings and infrastructure, also those generated by the construction of infrastructure, and those produced by natural disasters or catastrophes (as an example, considering only the houses affected by the 2010 earthquake, it is estimated that more than 20 million tons of CDW may have been generated) (3, 25).

On the other hand, 35% of solid waste comes from construction and demolition (26). In 2018, construction waste would have reached a volume of 4,822,361m^3, equivalent to more than 6.8 million tons per year and, according to MINVU, it is projected that by 2023 this will reach 7,455,602 million tons per year, which is equivalent to filling more than 15 times the National Stadium (26).

Also, it is estimated that between the years 2001 and 2019, the amount of CDW generated by the construction of buildings (with building permits), would result in an accumulated national total of 122.5 million tons (3), equivalent to more than twenty times the tons of fine copper production in the year 2019 in Chile.

2.4. Cost estimation in the construction process

Feasibility studies allow the client to estimate the order of magnitude of its investment, a process normally known as a conceptual estimation. In general, they can be performed based on general unit prices of similar works (e.g., \$/m^2), and by determining the size of the project, an approximate amount of the value of the work can be estimated (6, 27). On the other hand, planning and cost control efforts are crucial in the three main phases of a project: conceptual, design and execution, but their objectives and focus vary as each phase progresses.

Cost estimation is therefore one of the most common tasks of project management professionals. There are several methods for estimating, which depend to a large extent on the level of progress of the project, and which at the same time fulfill different functions in the development of the project. The selection of the appropriate method to perform the cost estimation is a function of the quantity and quality of the available information, which in turn will be greatly influenced by the stage of project development (6, 24). Therefore, an appropriate estimate in the initial stages of the project allows for deciding in time the direction the project should take in the future (6, 22), for example: to go ahead without modifications, to abandon the project (if unfeasible), or to make modifications in order to achieve the objectives, considering the constraints that affect the development of the project. In addition, a realistic conceptual estimate allows for the quantification of financing needs, considering the most appropriate mechanisms for the successful materialization of the project (28).

2.5. Study of budgets in construction projects

A construction budget is an estimate of the money needed to take a construction project from inception to closeout, including all associated costs and expenses that accrue during the construction process. While the budget is an attempt to forecast all costs on a construction project, it should leave some wiggle room to allow for emergencies or unexpected construction costs.

The total budget for a project can be subdivided into different items, as shown in Figure 2, which, when added together, determine the sales budget that is submitted to the bidding process.

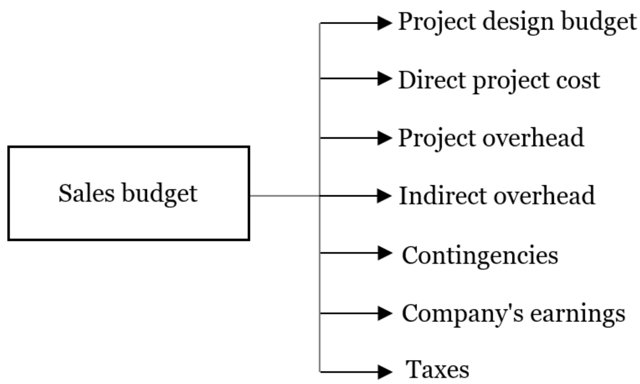

Figure 2. Outline of costs in a Construction Estimate. Source: Solminihac & Thenoux (6).

A construction budget is an excellent way to keep your project on track during execution. This starts once the call is made by the principal, where the contractor starts studying the proposal to bid Solminihac & Thenoux (6). The more expenses that have not been accounted for in a project, the longer it will take to finish. In addition, budgeting allows you to account for as many construction costs as possible and helps you stay on schedule.

The Unit Cost Analysis (UCA) can be defined as an advanced demonstration, in a standardized format, to analyze, break down and detail the performance of each unit cost of each item of a budget (per unit of work) (27, 29, 30). That is to say, it is the document that the contractor has as support to demonstrate the price of each item, executed in a period and according to pre-established conditions.

According to Solminihac & Thenoux (6), the steps to start studying a budget and elaborate on the UCA are:

1. Divide the work into items or payment items, which should consider all the expenses that will be incurred in the construction work. Once the budget is accepted, if any item has been omitted, in general, it becomes a loss for the contractor. The items must be measurable and controlla-

ble, to be able to quantify the progress of the work, collect payment statements and compare the actual progress with the scheduled progress. Solminihac & Thenoux (6) recommend that each line item be identified with a code, and also have a description or name. To facilitate this first step, the standard NCh. 1156 Of. 99. "Technical specifications for construction. Ordering and designation of items".
2. Determine the unit of measurement that each item will have. These units can be given in the technical specifications or be obtained from the standard NCh. 353 Of. 2000 "Measurements in building works".
3. Cubing the different items, i.e. calculating the number of units of each item, whether these are volumes (e.g. in cubic meters), areas (e.g. in square meters), lengths (e.g. in meters), etc. Likewise, the specifications are given in NCh. 353 Of. 2000 can be followed for cubing.
4. Estimate the cost of the item, i.e., its unit cost is studied, for which a unit cost analysis or base cost study of each of the components of the item is performed.

The direct cost or unit cost (U.C.) of an item must include all costs incurred to execute a job and must be compatible with the measurement and payment bases of the items. It is normally estimated through four components, which depend on the nature of the line item and the construction process used (6, 27, 30):

$$U.C.Item = U.C\ Labor + U.C\ Materials + U.C.Equipment + other\ costs \quad [1]$$

Cost analysis is a critical process in construction projects, being a complete breakdown of all costs to be incurred in performing any activity according to project requirements and specifications.

3. TYPIFICATION AND CODIFICATION OF WASTE GENERATED IN THE CONSTRUCTION INDUSTRY

If the production or waste process actors know with certainty the origin of their waste, the raw materials used, the production processes, and know the current regulations and a correct classification and typification, then the waste identification process will be considerably more effective (7, 8). Knowing, for example, whether the waste is hazardous or not, will help to decide the most appropriate type of treatment for the identified waste, thus helping to prevent harm to people and the environment (9).

3.1. European Waste List (EWL)

The European Union defines a European Waste List (EWL), which covers their classification using of the EWL Codes. This is a 6-digit code for each type of waste, while an asterisk next to the code indicates that the waste is considered hazardous. Wherein, it is composed of approximately 650 codes, and is divided into 20 chapters (2-digit codes) and subchapters (4-digit codes) according to the activities that generate such waste or the type of waste (31).

The European Waste List is the key document for waste classification. A well-elaborated classification will be the starting point for a decision on whether the waste is hazardous or not. Whether a waste is hazardous triggers several legal obligations for labeling, packaging, mixing, storage and transport. If the producers or holders of waste know how to identify it through the LER Code, they will be able to know what type of waste it is, in addition to its hazardous characteristics, and thus be able to decide the most appropriate type of treatment for the identified waste.

3.2. Ábaco-Chile: a construction cost database

The "Ábaco-Chile" project was awarded for the period 2015-2017, having funding by CORFO-INNOVA, and mandated by the Ministry of Public Works (Ministerio de Obras Públicas - MOP) and by the Ministry of Social Development. The main objective of the Ábaco-Chile project is the development of a public digital platform for the dissemination of economic costs and environmental indicators for the integrated management of construction projects in Chile (32). As a result of this project, an online platform is obtained that is used as a cost database in construction, focused on the preparation of construction budgets that include environmental parameters.

Correct classification of waste is essential to carry out a rigorous registration and control of the typology and magnitudes of waste generation in construction, as well as to evidence potential disposal alternatives or end of life of the waste (32, 33). As a basis for Ábaco-Chile, national normative elements were mainly considered, such as the Supreme Decree Regulation DS 148/2003, which defines the Safe Handling of Hazardous Waste, as well as the general guidelines established by the Law for the Promotion of Recycling (Law 20,920/2016). In addition to Chilean legislation, the information was complemented with the waste classification defined in the European Waste List (EWL) (31) according to Order MAM/304/2002 (34).Consequently, Ábaco-Chile is the first parametric database incorporating eco-efficiency indicators (sustainability and costs) for construction projects in Chile, which considers dynamic databases with the classification of resources and activities, technical specifications, environmental parameters and social costs, in order to measure the environmental impact from the design to the construction stage of a building (35, 36). In terms of functionality, Ábaco-Chile will provide an updated and freely available tool, and will also integrate binding information on costs and environmental and social indicators for public and private construction projects in Chile, providing the user with a working environment that considers resources, item data and budget (see Figure 3).

Therefore, Ábaco-Chile proposes a classification and coding structure for the resources used on-site, to generate construction budgets with environmental parameters.

In this sense, Ábaco-Chile proposes a classification and codification structure for the resources used on-site, to generate construction budgets with environmental parameters. Ábaco-

Chile classifies the basic resources used on-site in three categories: materials (MT), machinery (MQ) and labor (MO). In any budget, each concept must have a unique code that identifies it, so the three previous classes of resources are coded as MT, MQ and MO. On the other hand, the classification of Residues (RS) is shown in Figure 4, with their respective abbreviations, trying to make the nomenclature intuitive.

These abbreviations are arranged consecutively, maintaining their hierarchical order (class>subclass>type) to form the alphabetical part of the code. As regards the numerical section,

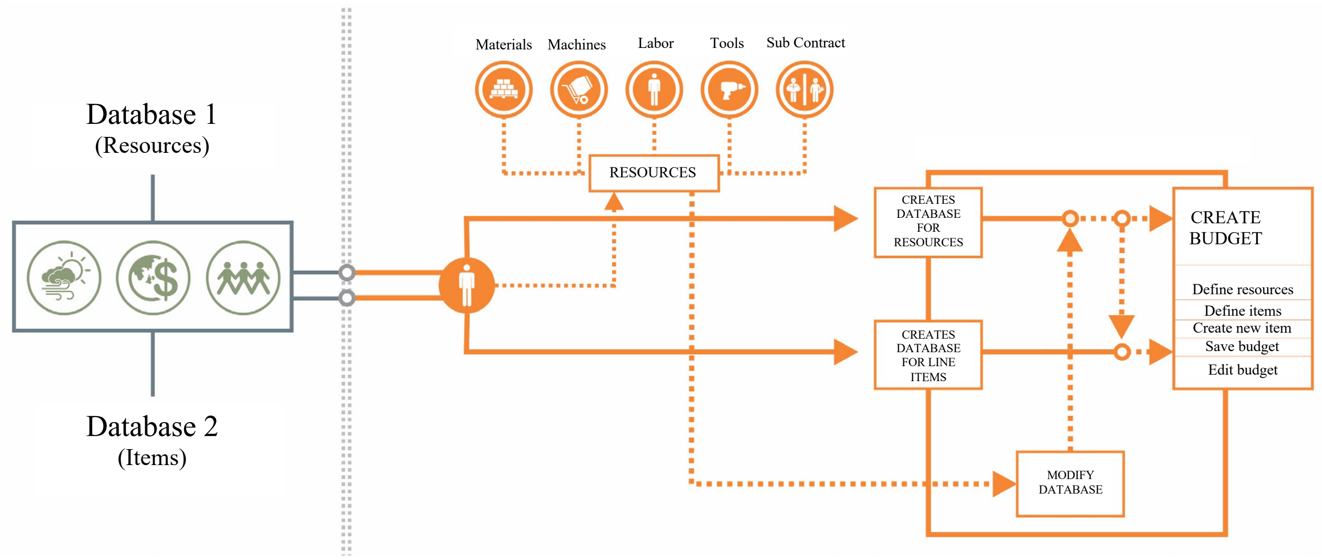

Figure 3. The functionality of Ábaco-Chile. Source: Ábaco-Chile (35).

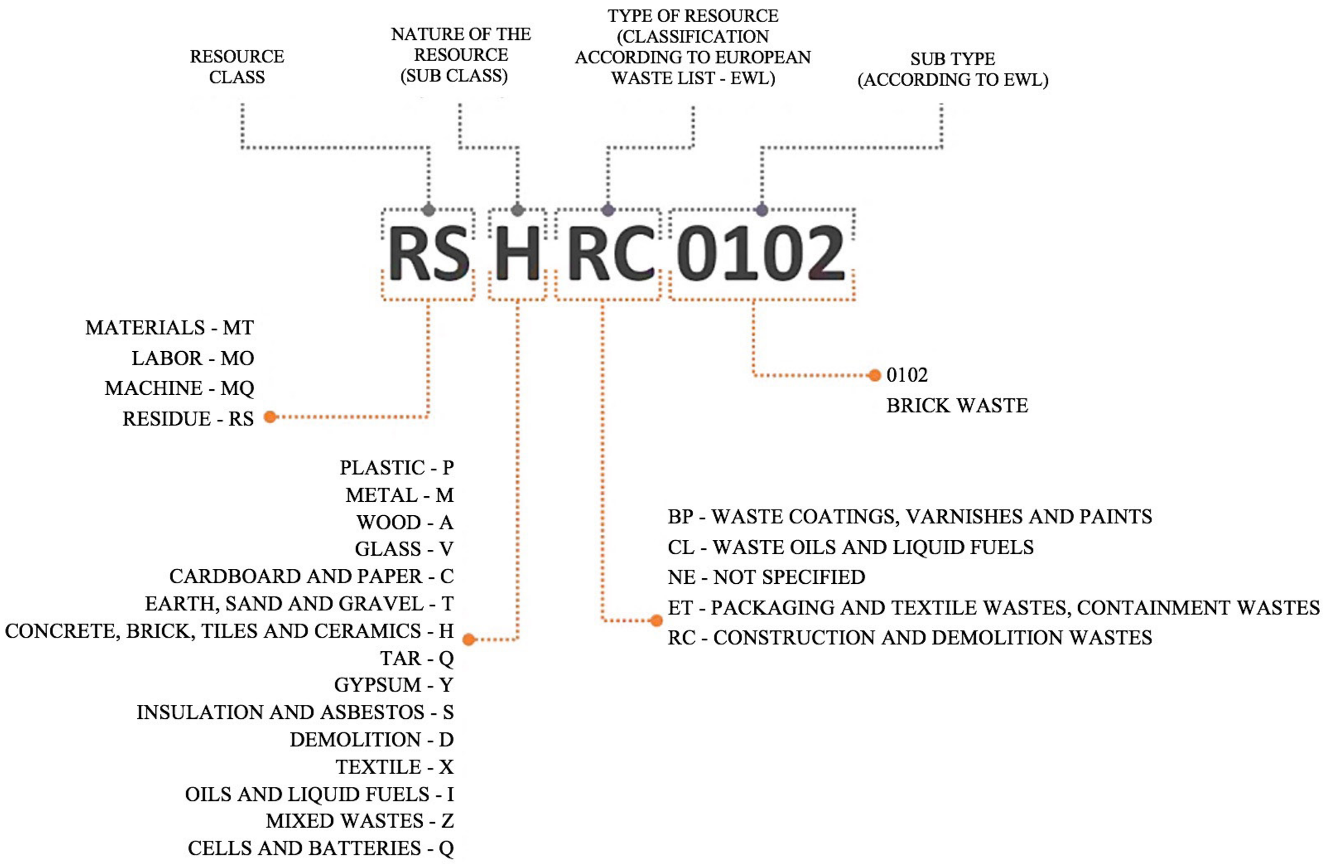

Figure 4. Example of waste coding according to Ábaco-Chile. Source: CITEC-UBB (32).

it is composed of the following four digits, which coincide with the digits of the respective code in the EWL. In order to supplement such information, the classification and coding of waste according to the European Waste List can be consulted (31).

4. METHODOLOGY

This research begins with a comprehensive literature review, according to the Web of Science, Scopus and Scielo databases. The literature review provided an updated understanding of the existing knowledge on waste generated in construction.

In the next stage, a methodology that incorporates quantification and cost in the budget study is proposed, also coding and classifying materials through Ábaco-Chile. This coding and classification method then proposes a classification and coding structure for the resources used on-site, oriented to generate construction budgets. This would also allow the identification and choice of different waste management options, know their hazardous characteristics, and thus decide

Table 1. Study Methodology.

STAGES	SUB STAGE	TARGETS
Bibliographic Review	Literature review on construction waste (general background in the world and in Chile, definition of waste, evaluation of sources, management plans, composition and quantification models of CDW, typification and classification of waste, etc.).	Definition of the conceptual basis of the research.
	Analyze the legislative framework in Chile that addresses the problem of waste generation and management.	
	Cost estimation and budgeting models for construction projects.	
Proposal in the UCA that incorporates a loss factor associated with a cost	Elaborate the UCA of a line item as an example, without considering typification according to Ábaco-Chile and Loss Factor associated to the cost.	Develop a methodology that incorporates quantification and costing in the budget study.
	Incorporate in the UCA the loss factor for each material that is associated with the cost (the loss factor is defined by the professional/company).	
	Type and classify the wastes generated from each UCA material, using the Ábaco-Chile.	
Validation of results	Develop a survey in order to estimate the percentage of loss of the most common construction materials that construction professionals would consider to be the most common.	Validation of results by experts.
	Statistical Analysis: a) Determine the probabilistic distribution of the % loss of each material; b) Estimate the range of the Loss Factor (%); and c) Determine the recommended percentage that could be considered for each material, through the Crystal Ball software.	
Conclusions and analysis of results	Answer the research question and make conclusions about the proposal made in the budget analysis study.	Establish guidelines to improve the budget study of a construction project.
	Recommendations and future research.	

Source: own elaboration of the authors.

the most appropriate type of treatment for the waste identified through the Ábaco-Chile coding.

The results are then validated through surveys carried out with experts in the construction sector. Finally, the results are concluded and analyzed, and future research is proposed.

5. PROPOSAL FOR A METHODOLOGY APPLICABLE TO THE PREPARATION OF UNIT COST ANALYSIS

5.1. UCA without considering the classification according to Ábaco-Chile and loss factor associated to cost

In this ACU format, which is the one used by construction companies in Chile today, the upper part identifies the project and type of item in the headings, and also indicates the quantity and unit of these items, indicating the unit of production of this item. Then, there are three large groups of data which are: materials, machinery equipment and labor (see Table 2).

The following is a typical unit cost analysis of a batch of H20 (200 kg/cm^2) foundation concrete, considering yields to generate one cubic meter of production. In addition, it is considered that for 120 liters. concrete mixer, 1 bricklayer, 2 workers, there is a yield of 2.7 m^3/day.

After completing all the values about what is required to be budgeted, the direct cost is calculated, which is the sum of these groups (A+ B+ C, i.e. materials, machines and tools, and labor respectively), where the Overhead (percentage of the direct cost prior analysis of the project), utilities (percentage of profit defined by each company), financial expenses (expenses incurred in the management of the work), VAT (value-added tax, which in Chile is 19%) are then added, thus completing the final value of the aforementioned item. This type of analysis is carried out for all the items in a similar way, so it is not necessary to exemplify with more items.

5.2. UCA considering classification according to Ábaco-Chile and loss factor associated to cost

A methodology is proposed that incorporates the estimation and cost associated with the waste generated in construction, incorporating a new column called "Loss Factor" to the Unit Cost Analysis that is associated with the cost per loss of a particular material, being a value, which can be represented in quantity or percentage, in which for ease of understanding is defined as a percentage, this value will be defined by the construction company or the professional in charge of the cost estimation. In addition, this proposed methodology incorporates the "Ábaco-Chile" typification of the waste generated by each material defined in the UCA. The following is a more detailed explanation of each column and information incorporated in this new UCA proposal, considering the typification according to Ábaco-Chile and the Loss Factor associated with the cost per loss of construction materials (see Table 3):

- Loss Factor (%): Variable that is incorporated into the Unit Cost Analysis (UCA), which is associated with the cost per loss of a particular material, being a value expressed as a percentage (%). This loss factor will be defined by the construction company or the professional in charge of the cost estimation, allowing the company bidding for a project to be more competitive and the client to see the costs associated with material losses.
- Loss Cost ($): Represents the cost of construction material losses as defined in the UCA. It is obtained by multiplying the "Loss Factor (%)" by the "Quantity" and the "Unit Cost" of the material, or by multiplying the "Loss Factor

Table 2. Unit cost analysis of "Concrete Foundations H20" without considering the typification according to Ábaco-Chile and loss factor associated with the cost.

UNIT COST ANALYSIS			
UCA: Concrete Foundations H20		Unit	Cubic Meters (m³)
Project: CCP Building		Quantity	1

A	MATERIALS				
N°	**Detail**	**Unit**	**Quantity**	**Unit Cost**	**Total**
1	Cement 25 kg	bag	10,00	US$ 5,08	US$ 50,8
2	Gravel 1"	m³	0,70	US$ 19,07	US$ 13,3
3	Coarse sand	m³	0,40	US$ 20,34	US$ 8,1
				Total A	**US$ 72,3**

B	MACHINES AND TOOLS				
N°	**Detail**	**Unit**	**Quantity**	**Unit Cost**	**Total**
1	Concrete mixer 120 liters	day	0,37	US$ 19,50	US$ 7,2
2	Wheelbarrow	c/u	0,01	US$ 317,80	US$ 3,2
3	Shovel	m³	1,00	US$ 0,17	US$ 0,2
				Total B	**US$ 10,6**

C	WORKFORCE				
N°	**Detail**	**Unit**	**Quantity**	**Unit Cost**	**Total**
1	Builder	day	0,37	US$ 38,14	US$ 14,1
2	Construction worker (2)	day	0,64	US$ 22,88	US$ 14,6
				Sub Total C	US$ 28,8
			55%	Social Laws	US$ 15,8
				Total C	**US$ 44,6**

D	Total direct cost (A+B+C)		US$ 127,4
E	10%	Overhead (on D)	US$ 12,7
F	3%	Financial Expenses (on D+E)	US$ 4,2
G	7%	Utilities (on D+E+F)	US$ 10,1
H	19%	Value-added Tax (on D+E+F+G)	US$ 29,3
TOTAL COST (D+E+F+G+H)			**US$ 183,8**

(%)" by the "Total" (remember that the "Total" column of the UCA is calculated by multiplying the "Quantity" by the "Unit Cost of the material"). Finally, by adding each material's loss cost, the total loss cost generated by all the materials of the item under study is obtained.

- Total Cost per Loss Cost: Represents the cost of the material plus cost per loss, where the construction company can analyze the total cost generated by the loss of each material. It is calculated as the sum of the "Total" (quantity per unit cost of the material) and the "Cost per loss" of each material.
- % Variation: It is calculated by dividing the "Total Cost per Loss Factor" by the "Total" in percentage terms.
- Waste Code: The waste typification for loss of each material in the ACU is considered, according to Ábaco-Chile.
- Waste Description: This describes the type or subtype of waste generated. It is at the discretion of the professional preparing the budget; however, it can be based on the "Type" classification used by Ábaco-Chile and/or the "Sub Type" classification incorporated by Ábaco-Chile and obtained from the EWL.

The Ábaco-Chile platform allows users to generate construction projects using resources available in databases or create their own resources by modifying an existing one. In this way, a budget can be built reporting the economic costs, segregating it into an analysis of unit costs, a list of resources, a list of general expenses and a list of social laws, thus allowing integrated information for early decision-making in the design. and execution of the project.

With this proposed methodology, the losses of materials will be known, where in this way the processes can be improved to lower these costs. In addition, an effective cost estimate also has an impact on the bidding process, since the higher the losses, the higher the cost for the client, which translates into less competition with other bidders. And, if losses are managed effectively or if processes are improved, there should be lower costs in losses that do not add value to the project.

Next, a new sub-table is proposed, associated with each material, which incorporates all the waste generated by each material, i.e., it does not only consider the waste generated by the loss of a specific material, but also considers the waste from the packaging or packaging of the material. This new column is called "Origin of Waste". For example, for a bag of cement, waste is generated by loss, which would be from the cement itself (mixed inert waste, RSHRC0101) and waste is also generated by the paper/cardboard bag containing the cement itself (RSCET0101). See Table 4.

Table 3. Unit cost analysis of "Concrete Foundations H20" considering the typification according to Ábaco-Chile and loss factor associated with the cost Unit cost analysis of "Concrete Foundations H20" considering the typification according to Ábaco-Chile and loss factor associated with the cost.

UNIT COST ANALYSIS

UCA: Concrete Foundations H20 — Unit: Cubic Meters (m³)
Project: CCP Building — Quantity: 1

A	MATERIALES								Residue Code (only for loss of material) (Ábaco-Chile)				Description Waste
N°	**Detail**	**Unit**	**Quantity**	**Loss Factor (LP%)**	**Unit Cost**	**Total**	**Cost of losses (LP% x Total)**	**Total Cost per Loss Factor (Total + Cost of losses)**	**RS**	**SC**	**T**	**ST**	
1	Cement 25 kg	bag	10,00	10%	US$ 5,08	US$ 50,8	US$ 5,1	US$ 55,9	RS	H	RC	0201	Inert mixed waste
2	Gravel 1"	m³	0,70	7%	US$ 19,07	US$ 13,3	US$ 0,9	US$ 14,3	RS	T	RC	0508	Gravel, gravel and sand wastes
3	Coarse sand	m³	0,40	4%	US$ 20,34	US$ 8,1	US$ 0,3	US$ 8,5	RS	T	RC	0508	Gravel, gravel and sand wastes
					Total A	**US$ 72,3**	US$ 6,3	**US$ 78,6**					
					% Variation	8,8%							

RS= Residue
MT: Materials
MO: Labor
MQ: Machines

T= Type
BP: Waste coatings, varnishes and paints
ET: Packaging and textile wastes, containment wastes
CL: Waste oils and liquid fuels
NE: Wastes not otherwise specified
RC: Construction and demolition waste

SC=Sub Class
P: Plastic
M: Metal
A: Wood
V: Glass
C: Cardboard and paper
T: Soils, sands and gravels
H: Soils, sands and gravels
Q: Tar
Y: Gypsum
S: Insulation and asbestos
D: Demolition
X: Textile
I: Oils and Liquid Fuels
Z: Mixed waste
O: Cells and batteries

ST= Sub Type
See European Waste List (EWL): http://data.europa.eu/eli/dec/2014/955/oj

B	MACHINES AND TOOLS				
N°	**Detail**	**Unit**	**Quantity**	**Unit Cost**	**Total**
1	Concrete mixer 120 liters	day	0,37	US$ 19,50	US$ 7,2
2	Wheelbarrow	c/u	0,01	US$ 317,80	US$ 3,2
3	Shovel	m³	1,00	US$ 0,17	US$ 0,2
				Total B	**US$10,6**

C	WORKFORCE				
N°	**Detail**	**Unit**	**Quantity**	**Unit Cost**	**Total**
1	Builder	day	0,37	US$ 38,14	US$ 14,1
2	Construction worker (2)	day	0,64	US$ 22,88	US$ 14,6
				Sub Total C	US$ 28,8
			55%	Social Laws	US$ 15,8
				Total C	**US$ 44,6**

			Without Loss Factor	With Loss Factor
D		Total direct cost (A+B+C)	US$ 127,4	US$ 133,8
E	10%	Overhead (on D)	US$ 12,7	US$ 13,4
F	3%	Financial Expenses (on D+E)	US$ 4,2	US$ 4,4
G	7%	Utilities (on D+E+F)	US$ 10,1	US$ 10,6
H	19%	Value-added Tax (on D+E+F+G)	US$ 29,3	US$ 30,8
		COST TOTAL (D+E+F+G+H)	**US$ 183,8**	**US$ 193,0**
		% Variation	5,0%	

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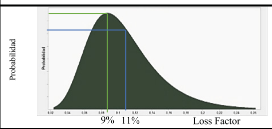
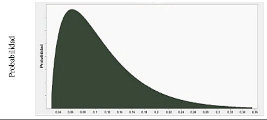
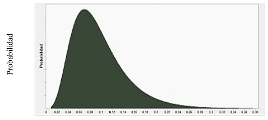
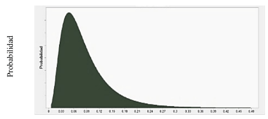
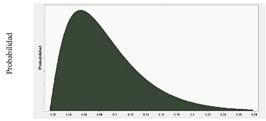
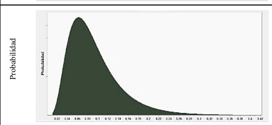
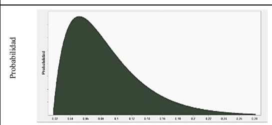
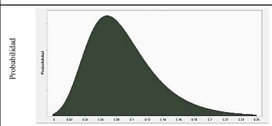
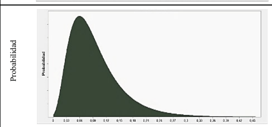
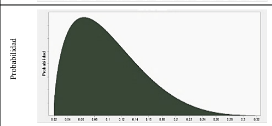
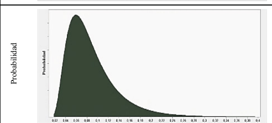
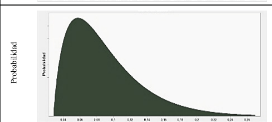
Table 4. Example of waste generated in a batch of "Concrete Foundations H20".

N°	Resources	Unit	Origin of Waste	Ábaco Code	Description Waste
1	Cement 25 kg	bag	Losses	RSHRC0101	Mixed inert waste
			Packaging	RSCET0101	Uncontaminated paper/cardboard packaging (paper bag)
			Packaging	RSARC0201	Wood waste (pallet)
2	Gravel 1"	m3	Losses	RSTRC0508	Gravel, gravel and sand wastes
3	Coarse sand	m3	Losses	RSTRC0508	Gravel, gravel and sand wastes

Table 5. Estimate of the loss factor (%) associated with the cost of the most incident construction materials.

N°	Material	Probabilistic distribution	Probability distribution graph	CI[1] 5%	CI 95%	Std. Dev.[2]	Average	Most Probable Loss Factor (%)
1	Ceramic tile	Maximum extreme		5%	19%	4%	11%	9%
2	Gypsum Plasterboard	Gamma		4%	23%	6%	11%	6%
3	Gypsum	Logarithmic normal		3%	19%	5%	10%	7%
4	Ceramic Tile Adhesives powder	Logarithmic normal		2%	20%	6%	9%	5%
5	Mortar (masonry)	Gamma		3%	19%	5%	9%	6%
6	Wall mounted paper	Logarithmic normal		3%	20%	5%	9%	6%
7	Paint	Gamma		3%	19%	5%	9%	5%
8	Cement	Maximum extreme		3%	18%	5%	9%	7%
9	Sand	Logarithmic normal		3%	21%	6%	10%	6%
10	Steel bars (reinforcement)	Beta		3%	20%	5%	10%	6%
11	Brick	Logarithmic normal		4%	18%	5%	9%	6%
12	Timber (Timber Stud Wall)	Gamma		4%	18%	5%	9%	6%

[1] Confidence Interval
[2] Standard Deviation

6. VALIDATION OF RESULTS

A survey is prepared in order to estimate the percentage of loss associated with the cost of the most incident materials, i.e., those materials that generate the most waste in construction. Professionals of the construction sector would estimate the percentage of loss through the survey, where for this, the sample size must be calculated, to know how many construction professionals need to be surveyed.

Once the survey has been carried out, the range of the Loss Factor (%) and the one recommended by experts will be estimated, which will be done through software that allows simulations and statistical analysis. For this, Crystal Ball will be used, being an analysis tool that allows users to make decisions by performing simulations on spreadsheet models. In addition, Crystal Ball is the simplest method to perform simulations using the Monte Carlo method in a spreadsheet.

Twelve materials were selected, which are the most incident materials, that is, those materials that generate more waste in construction, according to Bravo (37), who determined through a survey of 38 professionals the most incident materials; and according to Rodrigo Caniullán and Carlos Fuentealba (38), who surveyed 55 professionals, to determine the most incident items, wherefrom those items the materials that generate more waste on-site were selected.

Based on the above, the materials selected for construction professionals to estimate the percentage of loss associated with the cost are: ceramic tile, gypsum plasterboard, gypsum, ceramic tile adhesives powder, mortar (masonry), wall mounted paper, paint, cement, sand, steel bars (reinforcement), brick, and timber (timber stud wall).

Of the 71 respondents, 48% were Civil Engineers, 25% Civil Builders, and 18% were Construction Engineers.

7. LOSS FACTOR ESTIMATION (%)

Based on the results of the survey, in which 71 construction professionals estimated, according to their experience and criteria, the loss factor (%) associated with the cost of the 12 most common construction materials. Once the survey results were obtained, the probabilistic distribution of the 12 construction materials was calculated using Crystal Ball software, since it facilitates Monte Carlo simulations in a spreadsheet. In addition, the goodness-of-fit analysis of each probabilistic distribution is calculated for each selected building material.

Table 5 presents the probabilistic distribution that best fits each selected building material, with its confidence interval (CI) of 5% and 95%, the standard deviation, the mean and the most probable loss factor (%), which would be the most recommended.

8. CONCLUSIONS

The construction industry is traditionally environmentally unfriendly. The environmental impacts of construction waste include soil contamination, water pollution and landscape deterioration. In addition, construction waste has a negative economic impact by contributing additional costs to construction due to the need to replace wasted materials. However, to mitigate waste, construction companies should explore management options, which include waste reduction, recycling and disposal.

The reduction has the highest priority among waste management options, but efficient reduction cannot be achieved without proper identification of waste sources (39-42). That is why it is necessary to typify and classify waste, which is why this study incorporated Ábaco-Chile in the Unit Cost Analysis, where it would allow future identification and choice of different waste management options, and would provide information and guidance on whether the waste is classified as hazardous or non-hazardous. Therefore, if the producers or holders of waste know how to identify them through Ábaco-Chile, they will be able to know what type of waste they are, as well as its hazardous characteristics, and thus be able to decide the most appropriate type of treatment for the identified waste.

Excessive waste of materials, inadequate on-site management and low awareness of the need to reduce waste are common on construction sites. The enormous increase in the amount of waste generated due to the growth of the construction industry can lead to waste materials that have significant economic value. For this reason, a loss factor (expressed as a percentage) was incorporated in this study, which is associated with the cost of the material, where this loss factor will be defined by the construction company or the professional in charge of the cost estimation, allowing the company bidding for a project to be more competitive and the client to see the costs associated with the loss of materials, thus benefiting both parties.

As an example, for the item that was used in this study to explain the proposed methodology, "Concrete Foundations of H20", if the company in the bidding stage estimates a loss factor of 10% for cement, 7% for Ripio 1" and 4% for coarse sand, the material costs of this item can be considered 8.8% more, The total cost of the item (considering also labor, tools/machinery, general expenses, financial expenses, utilities, VAT) can be considered an additional 5%, that is, the percentage variation without considering the loss factor and considering the loss factor in the materials is 5.2%.

On the other hand, this study incorporated a statistical study for the most probable loss factor (%) of the most incident materials in the generation of construction waste. For this purpose, 71 construction professionals were surveyed and, based on their experience and criteria, they were asked to estimate the loss factor (%) of the 12 most incident materials. For each material, the probabilistic distribution that best fits were determined, calculating also the confidence interval (5%-95%), the mean, the standard deviation, the average and the most probable loss factor, among other statistical data, where the most probable loss factor for ceramics is 9%, for plasterboard 6%, for gypsum 7%, for ceramic powder adhesive 5%, for mortar 6%, for wallpaper 6%, for paint 5%, for cement 7%, for sand 6%, for framing 6%, for brick 6% and partition wood 6%. Of the 12 materials studied, ceramics is the construction material with the highest loss factor associated with cost.

It should be noted that none of these materials conform to a normal distribution, which means that the Gaussian bell is not symmetrical, nor are the mean, median and mode at the center of the curve, and their values do not coincide, neither does it reach its maximum (the maximum point of the Gaussian bell) at the mean as is the normal distribution, but in the 12 materials studied the Gaussian bell is asymmetrical, skewed to the right (positive skew), which implies that the mode is less than the median, and this in turn less than the mean (Mode<Median<Mean). Therefore, knowing the shape of the Gaussian bell allows for characterizing the data in terms of its uniformity and degree of concentration in the central region of the data distribution, in this sense, the symmetry of the data is related to the measures of central tendency for quantitative variables, where the asymmetric or skewed state is due to the sensitivity of the mean to outliers.

On the other hand, client demands and regulations are recognized as the main driver of change by Chilean construction companies. However, government regulations and policies are scarce and the ministries related to the construction industry should play a more active role in the creation and promotion of regulations and policies for the sector. That is why there are need for the education of owners and construction companies, the generation of regulations and policies to enforce the implementation of sustainable construction practices, and the implementation of financial incentives for sustainable projects to reduce owners' risk-taking aversion Therefore, it is important to know with certainty the quantification and estimation of costs from the planning phase of the construction project, since in this phase the costs are lower, but their influence on the costs is significantly higher.

In addition, the goal of all companies is to generate profits, so the implementation of sustainable construction and waste management practices within the company should be recognized as an opportunity to create value. Therefore, more research is needed to evaluate the economic impacts of sustainable construction actions (techniques and processes) implemented on construction sites, so construction companies should be well informed about those practices that will balance environmental protection and costs appropriately.

This study proposes a model to estimate the cost of construction waste, at the bidding stage, where a reliable estimation of the cost of construction waste before the start of construction activities will help decision-makers to better understand the cost implication of waste generation and improve their decision making in developing the appropriate strategy that can mitigate waste. Also, the results of this study show that waste is an important factor contributing to the cost of construction. A cost offered in the bidding, the losses of the resources are incorporated into the final amount offered, so that with the proposed methodology the losses of the materials of each item will be known, where the processes can be improved to lower these costs. It should be noted that the estimation of costs and valuation also has an impact on the bidding process, since the higher the losses, the higher the cost to the client, resulting in less competition with the other bidders. And, if losses are effectively managed or processes are improved, there should be lower costs in losses that do not add value to the project.

In the future, project stakeholders can evaluate and estimate the likely cost of waste using the method developed in this study, defining the loss factor associated with the cost of each material, and typifying and classifying the waste in the project planning phase, in order to be more transparent and competitive when bidding for a construction project, and to decide in advance the most appropriate type of treatment for the identified waste, which involves savings in total project costs.

On the other hand, investigations could consider a new waste cost factor, adding one that incorporates the cost of disposing of this waste, for example, knowing the scope of the contribution and the cost implication of the incorrect location, and, to facilitate decision-making, use can be made of Information and Communication Technology (ICT), based tracking systems, such as radio frequency identification devices (RFID), which can mitigate incorrect location and abandonment of materials in large construction works, and the implementation of Lean Construction methodologies, in order to improve the traditional construction management model through the identification and reduction or elimination of losses and activities that do not add value to the project.

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