CIRCULAR BUILDINGS

Calculation Tool:

Methodology Note

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REPÚBLICA PORTUGUESA AMBIENTE E AÇÃO CLIMÁTICA

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SMART WASTE PORTUGAL BUSINESS DEVELOPMENT NETWORK

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3drivers engenharia inovação ambiente

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1 INTRODUCTION

This document details the methodology of the Circular Buildings calculation tool. The calculation tool enables the interested user to estimate the environmental and economic impact of the end-of-life treatment of a building and its elements. The aim is to promote the increase of the reuse and recycling of construction products by quantifying the benefits of these waste treatment scenarios in comparison to landfill, in terms of cost and greenhouse gas (GHG) emissions. The scope of the calculation tool is the analysis of new construction. The geographical scope of the tool's database is Portugal, however, whenever there was a lack of Portuguese-specific data, European data was included.

The calculation tool is an output of the Circular Buildings project, which is funded by EEA grants under the Environment, Climate Change and Low Carbon Economy Programme. The project seeks to increase the application of Circular Economy principles in the construction sector through the development of decision support tools directed at stakeholders in the value chain, which promote an increase in the reuse of materials and a reduction in the production of waste. In addition to the calculation tool, three guidelines were developed within the project, namely the "Guideline for creating Circular Material Passports", "Guideline for improving efficiency indicators of buildings" and "Guideline for promoting circularity in Environmental Product Declarations".

2 CONCEPTUAL DESCRIPTION

The Circular Buildings calculation tool analyses the impacts of linear and circular material flows. The tool is based on an integrated building product database and requires additional input from the user regarding the building project. All components of the tool are set up in MS Excel.

The results of the analysis are expressed in material quality and quantity, GHG emissions and economic impact. The calculation tool can be used to analyse a complete building, as long as the user provides the material inventory, or for a selected number of building products. A wide range of users can benefit from the calculation tool. It uses a categorization hierarchy of building products that even allow a user without specific knowledge in the field, to conduct an analysis. However, for the interpretation and possible decision-making processes, an expert, such as a life cycle assessment (LCA) consultant or an engineer, should be consulted. Figure 1 shows an overview of the calculation tool. The different components of the calculation tool, namely user input, database and analysis, are explained in section 3.

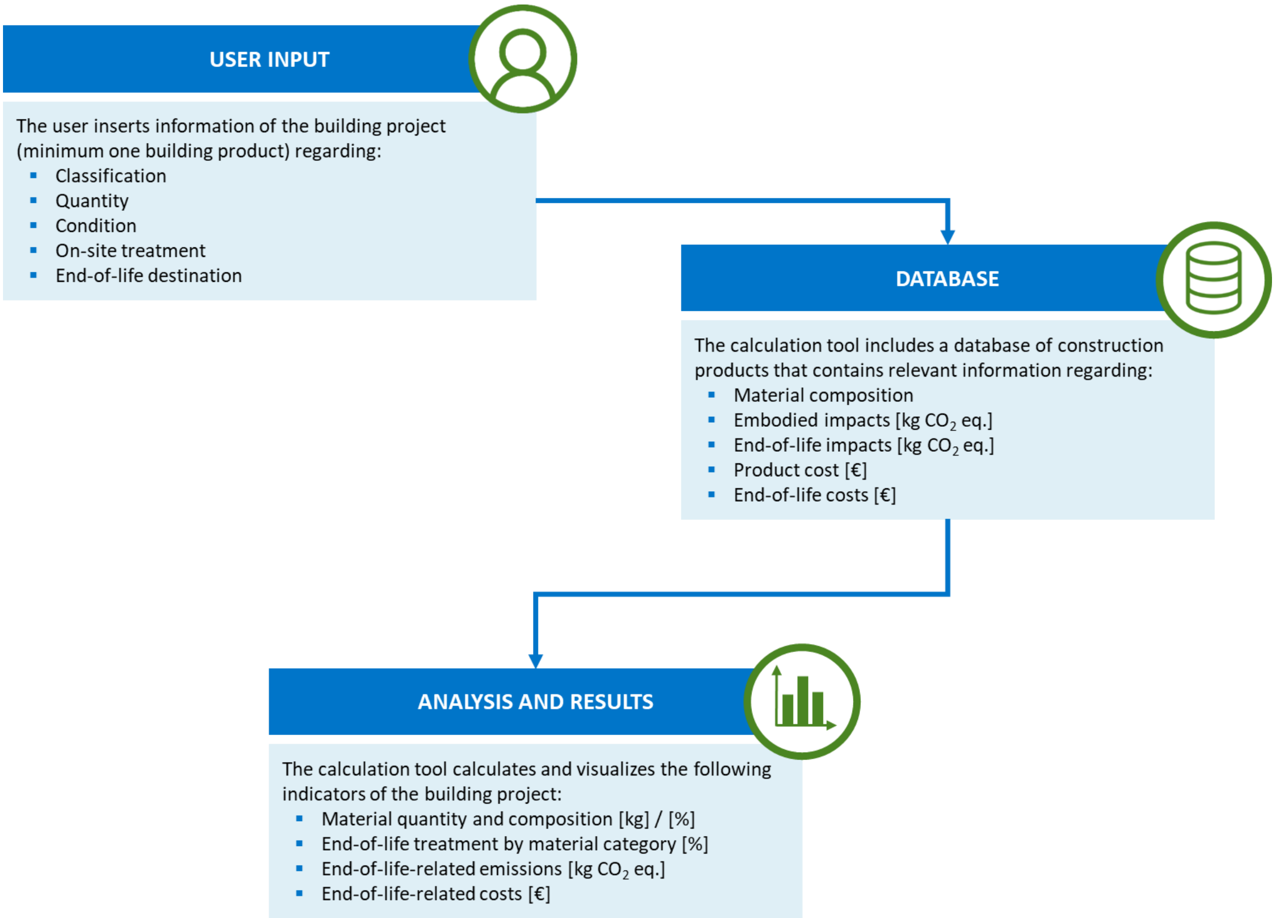

Figure 1: Conceptual overview of the calculation tool

3 COMPONENTS OF THE CALCULATION TOOL

3.1 REQUIRED USER INPUT

An overview of the required parameters that the user needs to provide for an analysis with the calculation tool is shown in Table 1.

Table 1: Overview of required user parameters in the calculation tool

PARAMETER	DESCRIPTION	TYPE OF PARAMETER
PROJECT	Name of the project Building address Location of analysed building elements (if applicable)	Open answer (text)
DESCRIPTION	Additional information about the project, building owner, and user	Open answer (text)
CONSTRUCTION PRODUCT	Category	Closed answer / unique selection from a list (refer to Annex A)
	Sub-category	Closed answer / unique selection from a list (refer to Annex A)

PARAMETER	DESCRIPTION	TYPE OF PARAMETER
	Construction element	Closed answer / unique selection from a list (refer to the database for an overview of all product entries)
	Quantity	Open answer (number)
	Unit	Closed answer (unique selection from a list)
	Condition	Closed answer / unique selection from a list: ▪ Good; ▪ Medium; ▪ Bad
	On-site treatment	Closed answer / unique selection from a list: ▪ Demolition and storage – mixed; ▪ Deconstruction, sorting and storage – separately
	End-of-life destination	Closed answer / unique selection from a list: ▪ Reuse; ▪ Recycling; ▪ Landfill.

3.2 DATABASE

The database contains information about product specifications, environmental and economic impacts. The information included is a mix of product- and manufacturer-specific data, average data (from one industry, for example), and generic data.

The data on environmental impacts was collected from different sources, including environmental product declarations (EPD). For the specific reference per product, please refer to the database itself. Hereafter an overview of sources that were used for the data collection:

[1] Inventory of carbon and energy (ICE) Version 1.6a

[2] WARM Greenhouse gas emission factors in the waste reduction model (2020)

[3] Greenhouse gas emission factor for mixed construction and demolition waste (2012)

[4] DAP Habitat system for EPD in Portugal (2021)

[5] EPD programme at IBU (2021)

[6] The International EPD System (2021)

[7] Gerador de preços Portugal (2021)

[8] Typical service lives for building parts from the EU Level(s) framework (2021)

The information on prices was retrieved from websites of home improvement retailers in Portugal[1]. For the specific reference per product, please refer to the database itself.

The database is a collection of data entries in MS Excel. The open structure of the database allows the user to include more products by simply adding lines. An overview of the database parameters can be seen in Table 2. Please note that the end-of-life economic impacts of the product can be positive (i.e. costs) or negative (i.e. benefit).

Table 2: Overview of database parameters

CATEGORY	PARAMETER	UNIT	SOURCE OF ENTRY
GENERAL PRODUCT INFORMATION	Category (refer to the Annex A)	--	--
	Subcategory (refer to the Annex A)	--	--
	Construction element	--	--
	Description	--	External
	Manufacturer	--	External
	Product unit	kg, tons, m^2, m^3	External
DETAILED PRODUCT INFORMATION	Weight per unit	kg	External
	Density	kg/m^2 or kg/m^3	External
	Material composition	%	External / Assumption
	Link to data source	--	--
EMBODIED ENVIRONMENTAL IMPACTS OF THE PRODUCT	Functional unit	units, kg, tons, m^2, m^3	External
	Carbon coefficient for the LC stages A1-A3 according to EN 15978	kg CO_2 eq.	External
	Reference service life	years	External
	Link to data source	--	--
END-OF-LIFE ENVIRONMENTAL IMPACTS OF THE PRODUCT	Carbon coefficient for reuse of the product	kg CO_2 eq.	Internal
	Carbon coefficient for recycling of the product	kg CO_2 eq.	Internal
	Carbon coefficient for landfill of the product	kg CO_2 eq.	Internal
	Notes	--	--
MARKET COST OF THE PRODUCT	Minimum market cost of the product	€/product unit	
	Maximum market cost of the product	€/product unit	

[1] Prices were researched in the following home retail stores: Leroy Merlin (https://www.leroymerlin.pt); Rei da Cerâmica (https://reidaceramica.com/); Loja dos Telhados (https://www.lojadostelhados.pt/); Colour of Stone (https://colourofstone.com/pt-pt/); Centibase (https://centibase.pt/pt/homepage); Macovex (https://macovex.pt/); IKEA (https://www.ikea.com/pt/pt/). All websites were last accessed on 25.08.2021.

CATEGORY	PARAMETER	UNIT	SOURCE OF ENTRY
	Mean market cost of the product	€/product unit	External or Internal (Average of minimum and maximum cost)
	Link to data source	--	--
END-OF-LIFE ECONOMIC IMPACTS OF THE PRODUCT	Cost for reuse of the product	€/product unit	Internal
	Cost for recycling of the product	€/product unit	Internal
	Cost for landfill of the product	€/product unit	Internal

Note to Table: In the column "Source of entry", *External* refers to external data sources [4–7]; *Internal* refers to parameters that were calculated specifically for this calculation tool, based on the information found in [1–3,7,9–14] and the websites from home improvement retailers.

3.2.1 Reuse, recycling and landfill

The end-of-life treatments that are included in the database are reuse, recycling and landfill.

For the environmental impacts of reuse, the avoided production emissions of using a new product are considered. In the case of recycling, emissions are determined based on the difference between the emissions from a production with virgin raw materials and production with recycled materials. For landfill, the emissions arising from landfill, per material of the product, are considered.

The economic impact of the end-of-life phase is evaluated considering the cost for demolition or deconstruction, cost for transportation of the material from the building site to the waste treatment plant or to the reuse location, and the cost of the waste treatment process. The same three end-of-life treatments as for the assessment of environmental impacts were considered. For reuse, the original market value of the component is considered saved. In the case of recycling, it is considered that the recycled materials would be sold at their market value. The cost of landfill is established by local waste management companies.

Hereafter, a description of assumptions that influence the end-of-life impacts of these three waste treatment options.

Reuse

It is assumed that it is possible for all products to be reused except for binders, aggregates, glues and any other singular material that is used in admixtures. The reasoning behind this assumption is that it is impossible to recover singular materials from mixed construction products, e.g. it is impossible to recover cement from concrete. However, prefabricated concrete elements can be reused since it is assumed that a product that is installed in the building as one piece, can technically be removed as one piece from the building to be reused afterwards.

Recycling

It is assumed that it is possible for all products to be recycled except for glued systems, e.g. external thermal insulation composite system (ETICS), since it is technically very hard, if not impossible, to remove the different layers from a glued system and then recycle them separately.

Landfill

It is assumed that it is possible for all products to be sent to landfill. In reality there are different options for landfill, such as landfill for inert material and landfill for hazardous material. Instead of characterizing these different options separately, the database only contains one option, called “landfill”. However, the quantification of the carbon coefficient reflect the impacts of different types of landfill.

3.2.2 End-of-life scenario for mixed materials products

For the reuse and recycling of products that contain more than one material group, it is assumed that only the most dominant or valuable material is being recycled. The remaining materials are assumed to go to landfill. For example, for a door made from steel and insulation, it is assumed that if the door is sent to recycling, only the steel will be recycled, while the insulation material goes to landfill.

In this context, the terms most “dominant” and “valuable” material are understood as follows: The material that represents more than 50% of the total product weight is considered dominant. The most valuable material is defined through the economic value of recovered material according to Di Maria *et al.* [15] and Coelho and de Brito [10–12,14]: metals are more valuable than wood, which in turn is more valuable than concrete. The remaining materials are considered equally value and follow after concrete.

3.3 END-OF-LIFE ANALYSIS

The calculation tool relies on its integral database to quantify the end-of-life impacts of buildings. As described in section 3.2 and in Table 2, the database contains external information for building products that were collected from different sources, and internal information that was calculated specifically for this calculation tool.

The following subsections describe the data sources and the calculation method for the internal information that is contained in the database.

3.3.1 Data sources

The calculation tool was constructed using existing data sources, as described above. A thorough analysis was conducted to select the most adequate data sources and calculation methods. Various cross-checking and comparison between different data sources was conducted to identify the most robust ones and to ensure a viable approach. The conclusion from the literature research and preliminary analysis was that the indicators for embodied carbon from the Inventory of carbon and energy (ICE) [1] are the most adequate for the scope of the Circular Buildings calculation tool. For end-of-life impacts for reuse, recycling and landfill it was found that the WARM indicators from the U.S. Environmental Protection Agency [2] are the most suitable.

The ICE indicators were compared to results from different environmental product declarations (EPD) for selected products. The results can be seen in Figure 2. It was found that for most products the embodied carbon coefficients vary only in the range of ± 20%. However, for bio-based products made, for example, from cork or timber, the difference is much bigger as the ICE indicators do not account for biogenic carbon capture. For these products, embodied carbon indicators from EPD that do consider biogenic carbon were collected. Assumptions regarding specific products are directly noted in the database. For all other products, the ICE indicators are used in the calculation tool.

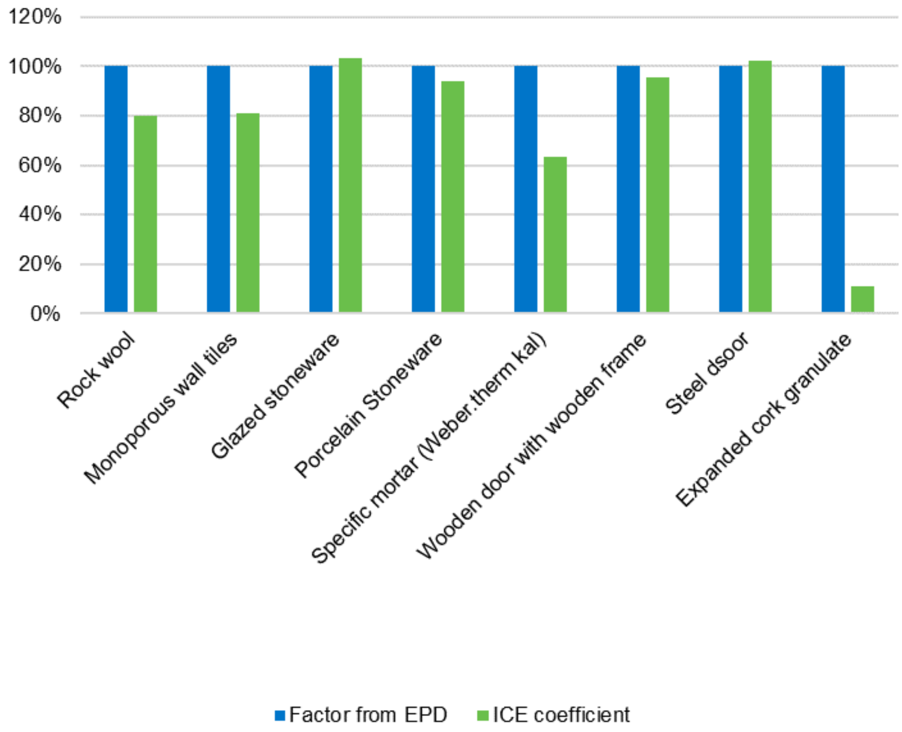

Figure 2: Comparison of embodied carbon from product-specific EPD and average ICE coefficients

The methodology of the WARM indicators was reviewed and once more for bio-based products it was found that the literature is not suitable. The WARM model assumes significantly high CH_4 recovery in landfill for electricity production and substitution of fossil fuels at grid. Since the WARM indicators represent the US waste model, the US energy grid is considered for the calculation of benefits from methane recovery. This is not representative for Portugal: the US generates 20% of its electricity from nuclear and 63% from coal and natural gas, while in Portugal only 43% are generated from non-renewable energy sources (coal and natural gas) [16]. Therefore, it was decided to use alternative data sources for products made from organic material: a sector EPD for medium density fibreboard (MDF) [17], and data from a Portuguese study [18] for dimensional lumber and wood flooring made from solid wood.

3.3.2 Environmental impact assessment

The **reuse impact** for each product that is stored in the database was calculated as follows:

$$EOLC_{Reuse} = -\frac{M_\alpha}{FU} * M_\alpha * EC_\alpha + \sum_{i-\alpha}\left(\frac{M_{i-\alpha}}{FU} * M_{i-\alpha} * LFC_{i-\alpha}\right)$$

if the product only consists of one material then ($M_\alpha = M_{total} = FU$):

$$EOLC_{Reuse} = -EC_\alpha * M_\alpha$$

The **recycling impact** for each product that is stored in the database was calculated as follows:

$$EOLC_{Recycling} = \frac{M_\alpha}{FU} * M_\alpha * RCC_\alpha + \sum_{i-\alpha}\left(\frac{M_{i-\alpha}}{FU} * M_{i-\alpha} * LFC_{i-\alpha}\right)$$

if the product only consists of one material then ($M_\alpha = M_{total} = FU$):

$$EOLC_{Recycling} = RCC_\alpha * M_\alpha$$

The **landfill impact** for each product that is stored in the database was calculated as follows:

$$EOLC_{Landfill} = \sum_{i}\left(\frac{M_i}{FU} * M_i * LFC_i\right)$$

if the product only consists of one material then ($M_\alpha = M_{total} = FU$):

$$EOLC_{Landfill} = LFC_\alpha * M_\alpha$$

Where:
EOLC are the product's end-of life-carbon emissions (in kg CO_2 eq.);
EC are the material's embodied carbon emissions for the LC stages A1-A3 according to EN 15978 (in kg CO_2 eq. per kg of material);
LFC are the material's carbon emissions for landfill taken from [2] (in kg CO_2 eq. per kg of material);
RCC are the material's carbon emissions for recycling taken from [2] (in kg CO_2 eq. per kg of material);
i are materials (according to the material categories listed in section 3.2);
α refers to the most dominant or valuable material, as described in section 3.2.2;
M is the quantity of a material (in kg), note that the total weight of the product is $M_{tot} = M_\alpha + M_i$;
FU is the functional unit of the product.

3.3.3 Economic impact assessment

The economic impacts of the end-of-life scenarios was calculated along the same lines as the environmental impacts that were described above.

The **cost for reuse** for each product that is stored in the database was calculated as follows:

$$EOLP_{Reuse} = -\frac{M_\alpha}{FU} * M_\alpha * OP_\alpha + \sum_{i-\alpha}\left(\frac{M_{i-\alpha}}{FU} * M_{i-\alpha} * LFP_{i-\alpha}\right)$$

if the product only consists of one material then ($M_\alpha = M_{total} = FU$):

$$EOLP_{Reuse} = -OP_\alpha * M_\alpha$$

The **cost for recycling** for each product that is stored in the database was calculated as follows:

$$EOLP_{Recycling} = \frac{M_\alpha}{FU} * M_\alpha * RCP_\alpha + \sum_{i-\alpha}\left(\frac{M_{i-\alpha}}{FU} * M_{i-\alpha} * LFP_{i-\alpha}\right)$$

if the product only consists of one material then ($M_\alpha = M_{total} = FU$):

$$EOLP_{Recycling} = RCP_\alpha * M_\alpha$$

The **cost for landfill** for each product that is stored in the database was calculated as follows:

$$EOLP_{Landfill} = \sum_{i}\left(\frac{M_i}{FU} * M_i * LFP_i\right)$$

if the product only consists of one material then ($M_\alpha = M_{total} = FU$):

$$EOLP_{Landfill} = LFP_\alpha * M_\alpha$$

Where:
EOLP is the price for the product's end-of-life treatment (in €);
OP is the material's original price (in € per kg of material);
LFP is the price for landfill of the material taken from [9,13,15] (in € per kg of material);
RCP is the price for recycling of the material taken from market inquiries (in € per kg of material);
i are materials (according to the material categories listed in section 3.2);
α refers to the most dominant or valuable material, as described in section 3.2.2;
M is the quantity of a material (in kg), note that the total weight of the product is $M_{tot} = M_\alpha + M_i$;
FU is the functional unit of the product.

Parameters for labour, transport and waste treatment costs

The total end-of-life cost consists of three components: cost for demolition, transportation and waste treatment. Each component is calculated based on different parameters. The formula and parameters for the end-of-life cost calculation can be seen in Figure 3.

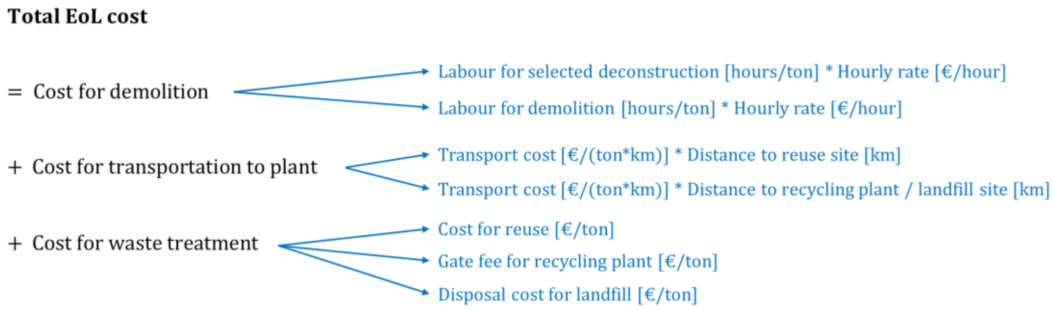

Figure 3: Parameters for the calculation of the end-of-life costs

The database includes average values for the required parameters for the end-of-life cost formula (as shown in blue in Figure 3). However, these parameters are highly uncertain as they depend on the location, type of construction, volume and composition of waste, labour and machinery used. The user is, therefore, highly encouraged to collect and employ site-specific parameters for their building project. The calculation tool allows to insert these parameters for the analysis.

3.3.4 Results

The calculation tool uses the user input and information retrieved from the database to analyse the following factors:

- Material quantity and composition [kg] / [%]
- End-of-life treatment by material category [%]
- End-of-life-related emissions [kg CO_2 eq.]
- End-of-life-related costs [€]

The results are visualized within the calculation tool using descriptive bar charts and pie charts. However, the user can extract the data to generate visualizations of additional factors in case that shall be required.

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ANNEX A - OVERVIEW OF CATEGORIES AND SUBCATEGORIES OF PRODUCTS IN THE DATABASE

CATEGORY	STORAGE AND CLOSET	BATHROOM	CONSTRUCTION	KITCHEN	GARDEN	FLOORS, WALLS AND COATINGS	DOORS, WINDOWS AND STAIRS
SUB-CATEGORY	Storage and closets	Bathroom furnishings	Plasterboard	Kitchen furnishings	Outdoor paving	Flooring	Doors
		Sanitary ware and other elements	Insulation	Sinks and fixtures	Garden furniture and other elements	Walls	Windows
			Cement, concrete and aggregates			Coverings	Staircases
			Cement glue and bitumen				
			Specific mortars				
			Roofs and coverings				
			Stairs				
			Plaster and stucco				
			Structural elements				

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