1.2.1. STUDY OF MOST USED MATERIALS IN CONSTRUCTION SECTOR IN PORTUGAL.

OERCO2

ONLINE EDUCATIONAL RESOURCE FOR INNOVATIVE STUDY OF CONSTRUCTION MATERIALS LIFE CYCLE

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1. Introduction

The construction sector is considered one of the most energy-consuming sectors in the EU, accounting for almost 40% of total energy consumption and contributing almost 36% to the EU's greenhouse gas (GHG) emissions. In addition to emissions, it also consumes a significant amount of natural materials and resources (energy, water, raw materials), generating emissions to air, water and soil, deposition and waste disposal.

Due to the relevant impacts of the construction sector on the environment, there are greater concerns and orientations towards more sustainable construction processes, with a special focus on the efficiency of the use of resources. Thus, proper use of materials, products and construction technologies promotes a more sustainable performance of building and construction works.

The great dimension of the construction sector and the environmental impacts from its activity are a major cause for concern, as excessive energy and raw material consumption for the construction of materials and buildings generate many environmental impacts. These excesses, allied with poor management of construction and demolition waste (CDW), sometimes deposited in illegal places without control or prior treatment, create a very worrying environmental situation.

In order to circumvent this set of situations, legislation and planning were created in order to mitigate the environmental impacts related to construction materials. In Portugal, the legislation on the standardization of rules for the marketing, production and disposal of building materials is adapted and/or used directly from European legislation.

To bridge the gap in CDW treatment and to promote the application of the waste management hierarchy, Decree-Law no. 46/2008 of March 12 was published, amended by Decree-Law no. 73/2011, of 17 June, which establishes the system of operations for the management of CDWs, including their prevention and reuse and their operations of collection, transport, storage, treatment, recovery and disposal. This decree is based on the European Waste Framework Directive 2008/98/EC, of 19 November, establishing a target of 70% for the reuse, recycling and recovery of the CDWs generated in Europe until 2020.

Regarding the products marketing, Decree-Law no. 130/2013 ensures compliance with the obligations arising from Regulation (EU) no. 305/2011 of the European Parliament and of the Council, of 9 March 2011, laying down harmonized conditions for the marketing of construction products. The Regulation also defines the conditions necessary for the affixing of the CE marking on construction products in accordance with the general principles described in European Union legislation. The CE marking means the conformity of the construction product with the performance declared by the manufacturer, corresponding to its essential characteristics.

There is also non-mandatory normalization and legislation, referring to Environmental Product Declarations (EPDs.) The overall objective of these declarations is to encourage the demand and supply of environmental friendly construction products by communicating verifiable and accurate information on the environmental aspects of these products, stimulating the market for the acquisition of products and services with continuous improvement of their environment performance. Thus, ISO 21930 provides the principles and requirements for type III environmental declarations (EPD) of building products, complementing ISO 14025 which refers to environmental labels and declarations for all types of products in general. Also, NP EN 15084:2012+A1:2013 provides the basic product category rules (PCR) applicable to all construction products and services. It provides a structure to ensure that all EPD relating to construction products, services and processes are prepared, verified and presented in a harmonized way.

In this context, basic requirement 7 of Regulation no. 305/2011 states that "for the assessment of the sustainable use of resources and the impact of construction works on the environment, Environmental Product Declarations should be used, when available", thus, although recommended, these standards do not require the use of EPDs.

The *Estratégia Nacional para as Compras Públicas Ecológicas* (ENCPE 2020), approved by Council of Ministers Resolution 38/2016, aims to act as a complementary instrument for environmental policies, contributing to the promotion of pollution reduction, consumption of natural resources reduction and, inherently, increasing the efficiency of systems. This strategy also intends that entities subject to the public procurement regime encourage the change of behaviour in society, promoting a new concept of development.

Accordingly, ENCPE 2020 applies the pre-contractual procedures defined in the Public Contracts Code, approved by Decree-Law no. 18/2008, of January 29. In this way, ENCPE 2020 is also covered by the point 7, article 8 of Decree-Law no. 73/2011, which requires "where technically feasible, the use of at least 5% of recycled materials, or incorporating recycled materials, in relation to the total amount of raw materials used on site, accordingly to the the contracting of construction and infrastructure maintenance contracts, under the Public Procurement Code ".

The promotion of efficiency in the use of resources is an integral part of a strategy to improve competitiveness and profitability at European level (COM 571/2011) and at the level of the company itself, with a "create more with less" perspective, obtaining higher value with less resources, using the resources in a sustainable way and reducing to a minimum their environment impacts.

This policy will also require materials and products to entail the lowest possible impact throughout all stages of their life cycle, from design, production, transportation and use to the end of life. Thus, innovation within companies is central to the adoption of measures and policies that promote sustainable practices at all levels with an appropriate cost. At the product design stage, it is essential, wherever possible, to avoid the introduction of hazardous substances and to provide for easier, safer and less expensive recycling and reuse options.

Although it is a relatively recent and very broad subject in Portugal, with few studies on the subject, Torgal & Jalali (2010) wrote about sustainable construction where it is emphasized that construction entities must prioritize materials that are:

- Non-toxic;
- With built-in low power;
- Recyclables;
- Which may allow the reuse of waste from other industries;
- Which come from renewable sources;
- Associated with low GHG emissions;
- Durable;
- Where a choice is made through an assessment of their life cycle.

The "life cycle thinking" approach to product development considering the environmental aspects and impacts throughout the life cycle is critical to identify hotspots for improvement and minimize environmental impacts throughout the life cycle of Avoiding the transfer of impacts from one phase to another.

On the other hand, the suitability of each material to its function is crucial in the selection and selection of construction products. The development of sustainability criteria for construction products should ensure that they are durable, safe, healthy, environmentally and economically designed at all stages of their life cycle. Thus, sustainability always considers environmental, social and economic criteria (CTCV, 2012).

Table 1 presents a proposal of criteria to be considered in the different stages of construction material's life cycle.

Life Cycle Stage	Proposal for Criteria
Extraction of raw materials and processing	Use of national resources
	Control of emissions (air, soil, water)
	Generated waste
	Recycled content
Production	Use of clean fuels (renewable energy)
	Ecodesign
	Control of emissions
	Generated waste
	Policies for reduction of consumption
	Environmental management systems
Transport	Packaging (reusable, % recycled material, recyclable)
	Type of transport
	Use of locally produced packaging
	Distances travelled
Use and maintenance	Durability (years)
	Human Toxicity
	Water Toxicity
	Emission of VOC's
	Low energy consumption
	Low consumption of cleaning agents
Decommissioning and end of life	Recyclability (%)
	Number of years of decomposition in landfill

Table 1 - Proposals of criteria for the different stages of the life cycle.

As part of the European strategy for improving building performance, Directive 2010/31/EU outlines the minimum requirements for improving the energy performance of buildings. It is transposed by Decree-Law no. 118/2013 of 20 August, which aims to ensure and promote the improvement of the energy performance of buildings through the Energy Certification System of Buildings (SCE), which integrates the Regulation of Energy Performance of Residential Buildings (REH), and the Regulation of Energy Performance of Commercial and Service Buildings (RECS).

Within this strategy, Directive 2009/28/EC on the use of energy from renewable sources, outlines the framework for improving the environmental performance of the energy mix. It is partially transported to the Portuguese reality by Decree-Law no. 141/2010, of December 31, which establishes the national targets for the use of renewable energy in gross final consumption of energy, as amended by Decree-Law no. 39/2013, of March 18.

These Directives indirectly allow to reduce the environmental impacts generated in the life cycle of construction materials and technologies, contributing to their sustainability.

2. Evaluation of the materials and operational solutions most used in construction

In Portugal, the most commonly used building solutions, especially in residential buildings, have remained practically unchanged for several years. The construction system is well-rooted and is used throughout the country, usually consisting of a porticoed structure with pillars and beams in reinforced concrete and slabs lightened. For the execution of the outer walls, a simple wall solution, also in ceramic brick, is currently used.

In the most recent Census in 2011, the Portuguese housing stock was constituted by more than 85% of buildings with only one housing unit and 84.9% of the buildings in the Portuguese housing stock were between one and two floors. With more recent construction, the proportion of buildings with one or two floors declined steadily in buildings, but remained above 75%. Although the proportion of isolated and banded buildings varied substantially in the different regions of the country, 60.5% were isolated and only had one or two housing units. Regarding construction methods, buildings built after the 1970s constituted 63.1% of the traditional construction buildings in Portugal's existing housing stock in 2011 (Mendes, 2013).

Table 2 shows the typology of the houses in Portugal by the number of bedrooms, according to the Decree-Law no. 650/15, of 18 November. This decree stablishes that the dwellings are distinguished by the number of rooms they have, starting from T0 upwards. The "T" means "typology" and the number after is referring to the number of rooms of the dwelling.

	Number or bedrooms	%
T0	61 720	1,0
T1	363 591	6,1
T2	1 219 572	20,6
T3	1333438	22,5
T4	551 355	9,3
T5+	528 182	8,9

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N/A	1 868 428	31,5
Total	5 926 286	100,0

Table 2 - typology of the houses in Portugal by the number of bedrooms (source: INE, 2015)

In 2011, almost half of the residential buildings had reinforced concrete structures (48.6%) and roughly one-third of the buildings had masonry walls with reinforced concrete slabs (31.7%). The remaining buildings had less representative structure types such as masonry walls without reinforced concrete slabs, loose stone or adobe masonry walls and other types of structure, respectively 13.6%, 5.3%, 0.8% (Mendes, 2013).

Table 3 shows the main types of construction used in the structure, exterior wall cladding and covering of residential buildings in Portugal.

Structure	
Material	%
Reinforced concrete	48,6
Masonry walls with reinforced concrete deck	31,7
Masonry walls without reinforced concrete deck	13,6
Loose stone masonry walls	5,3
Agglomerate	0,8
Exterior wallcovering	
Material	%
Traditional coats and granolithic concrete	84,0
Stone	11,6
Ceramic tile or mosaic	3,8
Other coatings	0,6
Roof	
Type	%
Inclined roof covered with ceramic or concrete tiles	93,1
Inclined roof covered with other materials	1,8
Mixed (inclined and terrace)	2,1
Roof terrace	3,0

Table 3 - main types of construction of residential buildings in Portugal (source: Mendes, 2013)

Regarding the building envelope, there is clearly a pattern of the existing building materials, as previously identified. On the other hand, for insulation purposes, there is a wider number of materials used. The most used materials for insulation are Expanded Polystyrene (EPS), Extruded Polystyrene (XPS), Polyurethane foam (PUR), Polyisocyanurate foam (PIR), Mineral Wool (MW) and Expanded Insulation Corkboard (ICB), as demonstrated in Table 4, that shows the main materials used for the construction of residential buildings in Portugal.

Materials	Walls			Roof			Pavements	Glazed span
	Insulation inside the air box	Thermal insulation from outside	Thermal insulation from inside	Horizontals	Inclined with garret	Inclined without garret		
Flat brick	x							
Solid brick	x	x						
Light concrete	x			x				
Reinforced concrete		x	x					
Normal Concrete	x	x	x		x			
Reinforced concrete slabs				x	x	x	x	
Lightened slab				x	x	x	x	
Expanded Clay Aggregates				x				
EPS	x	x	x	x	x	x	x	
XPS	x	x	x	x	x	x	x	
PUR	x	x	x	x	x	x	x	
PIR	x	x	x	x	x	x	x	
MW	x	x	x	x	x	x	x	
ICB	x	x	x	x	x	x	x	
Metal		x						
Wood					x			x
PVC								x
ETICS		x					x	
False ceiling							x	
Aluminium								x

Legend: PVC - Polyvinyl chloride; ETICS - External Thermal Insulation Composite Systems.

Table 4 - Main materials used for the construction of residential buildings in Portugal (adapted: ITeCons, 2012)

The regular use of this traditional constructive system is due to several factors, among them:

- Economic factors: the materials used come from abundant raw materials in the country, leading to a lower cost of construction compared to the use of non-local materials. In addition, there are many manufacturers of materials for the current construction and builders/contractors who master the technique of this type of construction, which provide a high competition, making these solutions more competitive and attractive;
- Low qualification of construction workers: the option for more technologically advanced constructive solutions implies the use of specialized labour, which is not always easy to find, since the construction market is unattractive for young people;

- Lack of training of construction technicians: there is still a gap in the training of architects and engineers regarding new constructive technologies, being mainly directed at current constructive solutions;

However, due to the implementation of certain regulations, such as the RCCTE, Regulation of the Characteristics of Thermal Behaviour of Buildings (Decree-Law no. 80/2006, of April 4), or the RRAE, Regulation of Acoustic Building Requirements (Decree-Law no. 96/2008, of June 9), there has been a greater need to implement constructive solutions that comply with the requirements imposed by the legislation. Regarding the RCCTE, it has given greater importance not only to the characteristics of the constructive solutions that make up the building envelope, but also to the use of renewable energy sources, as well as to the systems of climatization and hot water preparation.

3. Evaluation of the materials and sustainable solutions used in construction

In this chapter are presented some of the main sustainable solutions for construction materials and services. Some are non-conventional solutions that contribute to the sustainability of the construction industry and meet the new requirements that have been emerging in the construction market. Others are more traditional technologies, which have fallen into disuse over time, but which, through their use of natural materials, largely contribute to increasing the sustainability of construction.

This section is subdivided into two groups that distinguish the differentiation of the sustainable constructive solutions by means of the materials and by the innovation of the constructive method.

3.1. Construction materials

The optimization of the properties of the materials refers mainly to the alteration of its composition, whether with synthetic or natural materials, that leads to the improvement of its performance.

Table 5 shows some of the existing databases for materials for sustainable construction.

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Existing Databases for Sustainable Construction	
4Rs	Empowered by LiderA (voluntary system of sustainability assessment to certify built environments) in partnership with several institutions. It aims to provide information on the demand for sustainability of products and services.
MetaBase IteC (BETEC)	It belongs to the set of metaBase of the Institute of Construction Technology of Catalonia (ITeC), in Spain (www.itec.es), with information on construction products, namely, prices, technical specifications, commercial, certifications, product image and Environmental data.
ECOproduct	It is a tool to support the selection of building materials, built as part of a PhD thesis held at SINTEF Byggforsk, Norway. It is based on information contained in Environmental Product Declarations.
Colégio de Arquitetos de Valência	Directory of building materials developed at the College of Architects of Valencia (www.ctav.es) in Spain. These materials are classified from 1 to 10 in a broad set of ecological and economic criteria with weights assigned by that entity.
Productosostenible.net	Portal developed by the University of the Basque Country (Ecodesign class documentation centre) and Mondragón University, in partnership with several companies, associations and technology centres in Spain. In this portal, there is a database of industrial materials that contains information on the environmental improvements that these products present, based on Life Cycle Assessment (LCA) and Ecodesign (productosostenibe.net, 2011).
Green Guide	Guide to Bre Environmental Profiles (www.bre.co.uk), developed in the UK. It is specific to the construction industry and is based on the Life Cycle Assessment (LCA) methodology. In this Guide, information on the environmental impacts of building materials, measured throughout their life cycle, is presented in Environmental Profiles.
Cd2e - Le centre expert pour l'émergence des éco-technologies, ou service du développement des éco-entreprises	Association in Nord-Pas-de-Calais, France, which provides guidance on existing eco-structures or their development, supporting their growth and sustainability. This association has created an eco-material database, allowing to find the products that are most suitable and that conform to the requirements of the HQE standard.

CODEM – Construction Durable & Eco Matéraux	French Association for the development, acquisition and validation of technologies for sustainable construction and the use of green materials in an attempt to improve energy performance, reduce greenhouse gas emissions and use environmentally friendly materials (incorporate waste, etc.). On the website, there is a database with some eco-building materials.
COM.PRO: ecoCOMpatibility of PROducts	Database developed by the DINSE (Department of Human Settlements Science and Technology) of the Polytechnic Institute in Turin, Italy. It is based on environmental indicators and technical information.
EcoSpecifier	In this Australian database (www.ecospecifier.org) there is a set of materials and construction systems with a better environmental performance. It offers more than 6000 eco-products, eco-materials, technologies and resources that can be visualized through five modalities in which what varies is the quality and quantity of environmental performance information (existence of Life cycle assessment, environmental product declaration or other certification), as well as the cost.
Other materials databases (that have some information on the sustainability of these materials, although not always systematic or quantified)	**ConneXion Material:** Provides complete information on each of the materials, including images, detailed material descriptions, usage characteristics, and manufacturer and distributor information. Developed by an international team of multidisciplinary experts, aiming to contribute to bridge the gap between knowledge and design in order to develop practical solutions. (http://www.materialconnexion.com)
	Materia: Knowledge centre for developments and innovations in materials and their applications for architecture and design. It provides an advanced set of information on innovative materials, accessible in a free and user-friendly way. (Http://www.materia.nl)

Table 5 - Material databases for sustainable construction. (Source: CTCV, 2012)

Table 6 presents some construction materials that present characteristics considered more sustainable than most current materials, being organized by optimization of properties, innovation, natural insulation and inorganic insulation.

	Material	Sustainable characteristics
Improved properties	**Structural concrete**	Replacement of Portland cement with alternative binders to improve durability
	Mortar with cork incorporation	Incorporation of cork waste into mortar for thermal and acoustic behaviour
	Thermal plaster with EPS incorporation	Façade coating purpose with high durability and good thermal performance
Improved properties	**Paints with greater reflective capacity**	Addition of microspheres for greater reflectivity of infrared radiation and improved thermal and acoustic properties
	Concrete with expanded clay for the manufacture of blocks	Use of expanded clay with clinker coating for thermal performance improvement
	Expanded polystyrene with incorporated graphite	Addition of graphite particles to reduce thermal conductivity
	Resin coating with built-in cork	Thermal barrier, preventing energy losses and cracks, with fast and easy application
Waste incorporation	**Concrete**	Incorporation of CDW and waste tires into concrete to reduce waste generation for improved flexibility and sound insulation
	Mortars	Incorporation of glass, waste from industrial by-products to optimize the characteristics of hydraulic mortars and mortars with aerial binders, or waste from ornamental stone plants to reduce exploitation of natural resources and recycling of contaminated water during stone cutting
	Materials for the manufacture of blocks	Incorporating recycled CDW, cork waste, glass dust, or rice hulls to increase the mechanical resistance of the concrete and the reduction of its water absorption or incorporating residues of polystyrene for the reduction of its density
	Ceramics	Incorporation of industrial waste in the production of ceramic tiles, reaching up to 80% recycled material by weight while retaining the strength and versatility
Nanotechnology	**Aerogel**	High thermal and acoustic performance, stable when subjected to high temperatures, withstands humidity
	Phase change materials (PCMs)	The incorporation of these materials in construction products results in the reduction of the energy consumptions
Natural insulation	**Hemp**	The association of lime to hemp results in a building material, which allows rapid and efficient building, coupled with low carbon impact due to hemp's ability to absorb carbon dioxide
	Paper and cellulose pulp	The cellulosic pulp is the result of the recycling of cellulosic products, such as newsprint, not sold or used, thus reducing waste materials

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	Coconut fibre	Used as thermal and acoustic insulation, the transformation of this waste into new products contributes greatly to the conservation of the environment.
	Recycled cotton	Natural fibre, can be used as a building material, offering a high thermal and acoustic performance
Natural Insulation	**Fibre flax**	Allows the manufacture of products with high performance for thermal and acoustic insulation of buildings, which can be applied to walls, roofs and floors
Natural Insulation	**Straw**	Has a high mechanical strength and also fire resistance, due to its compactness, good performance in terms of thermal and acoustic insulation, can be used in the form of a composite material, such as wood fibres or waste tires
Natural Insulation	**Wool**	One of its characteristics is hygroscopicity, able to absorb more humidity than any other natural fibre, with good level of performance in terms of thermal and acoustic insulation, can be used for the insulation of walls, ceilings and floors
Natural Insulation	**Jute**	Their natural fibres can be used in the construction industry, especially in the reinforcement of polymeric composites in substitution of synthetic fibres
Natural Insulation	**Sisal**	Sisal derives from a plant, and its natural fibres can be used in the construction industry, used mostly in the manufacture of composite materials, stands out for the high resistance to impact, traction and flexion
Inorganic insulation	**Cellular glass**	Inorganic thermal insulation with closed cell structure, mainly made up of glass, having a high percentage of recycled glass or glass waste, and can also be recycled, does not require maintenance due to its durability
Inorganic insulation	**Expanded glass**	Impermeable to water vapor and therefore suitable for insulation of underground constructions in contact with soil and water, inert material, has a high durability and is imputrescible
Inorganic insulation	**Calcium silicate foam**	Open and rigid cell microporous foam, recommended for increased protection against moisture, especially in the rehabilitation of old buildings, high pH, which inhibits the appearance of fungi
Inorganic insulation	**Expanded perlite**	Good thermal and acoustic performance, used in the form of plates for the insulation of walls and ceilings and in composite materials, as is the case of perlite plates combined with mineral wool
Inorganic insulation	**Vermiculite**	Group of hydrated laminar minerals, low density, low thermal conductivity, resistance to high temperatures, great absorption capacity, used as thermal and acoustic insulation

Table 6 – Different types of sustainable materials used in construction (source: adapted from ITeCons, 2012; CTCV, 2012)

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3.2. Construction methods

The concept of "eco-efficient" construction has often been associated with the reduction of energy consumption in buildings, and is therefore confused with the concept of bioclimatic architecture. However, the concept of eco-efficient construction is more comprehensive, including concerns on reducing the depletion of natural resources and the production of waste and the emission of pollutants harmful to ecosystems and human health.

Thus, in addition to sustainable building materials, construction techniques can also contribute to the improvement of the building's environmental performance. Table 7 shows some sustainable construction methods, including less current methods but also innovative methods.

Construction method	Sustainable characteristics
Pre-fabrication	Contributes to the reduction of a large part of the waste compared to the traditional in situ construction; Possibility of designing the product considering its deconstruction and reuse; Reduction of on-site energy consumption.
Rammed earth	Low environmental impact, depending on the amount of cement used in the stabilization processes and the distance to the site where the soil is extracted; Incorporated energy and associated greenhouse gas (GHG) emissions are very low when the cement quantity is small.
Adobe	Although a large amount of water is used, only a small amount of power is required for its execution, so the energy incorporated in this type of construction is usually low and the greenhouse gas (GHG) emissions associated with this solution are very small.
Light Gauge Steel Framing – LGSF	This constructive system is more sustainable from the point of view of the preservation of natural resources. Energy consumption that occurs during its extraction and manufacture can be amortized over a longer period of time; Allows the use of lighter means of transport and yard equipment, which reduces the energy consumption in transport, lifting and assembly operations; Production processes are extremely controlled, allowing the reduction of waste, energy resources associated with assembly, disassembly, cleaning and storage operations.

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Autoclaved cellular concrete	Per unit weight, the environmental impacts are similar to those of concrete, but as the weight per unit volume in this product is about 1/4 to 1/5 of the weight of the concrete, the environmental performance is better; The good thermal insulation of this material reduces the need to resort to mechanical means of conditioning the interior temperature; The amount of raw material required for this constructive system is low when compared to conventional systems, thus contributing to the preservation of natural resources; Its low weight also enables the use of lighter transport and lifting means, so the energy consumption in these operations can be reduced; The high degree of industrialization associated with this technology, translates into the production of less waste.

Table 7 - Sustainable solutions used in construction (source: ITeCons, 2012)

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