INTELLECTUAL OUTPUT 1

TASK O1-A2
Sustainable construction methods and procedures used for Circular Economy concepts

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INTRODUCTION

This report is included in the task *"O1-A2. Sustainable construction methods and procedures used for Circular Economy concepts"*, corresponding to Intellectual Output 1 "*Establishment of common learning outcomes on placing methods based on circular economy criteria, Life Cycle Assessment (LCA) and relative regulations*" of the CircularBIM project.

This report is the result of an analysis of the methods, skills and competences related to construction products. Different installation and construction methods applied in the construction industry have been assessed in order to extend the lifetime of these products by using the most sustainable installation methods selected.

A best practice report has been developed with the aim of transferring successful methodologies and pedagogical strategies to improve the training system.

Environmental methods and last investigation have been taken into account, such as erosion/revelation within manufactured construction products for its application on nZEB (net-Zero Energy Building) projects or the use of new technologies.

All the information about the project and more technical documentation is available in the following url:

- CircularBIM project web: www.circularbim.eu

CONTENT

1. INTRODUCTION

With the growing problem of global warming, it is necessary to study the efficiency of resources, which in the building sector begins by acting on the reduction of construction and demolition waste, to reduce it as much as possible. For this it is necessary to anticipate the moment in which the projects are designed, where the use of new technologies will help the implementation of criteria of optimization of resources based on the concept of circular economy.

Although there is no exclusive system of indicators to evaluate circularity in the construction sector, the previous paragraph already indicates that the solution lies in improving resource efficiency, the reduction and correct management of construction and demolition waste (CDW) is the key to achieving this objective. At present, only 40.9% of the declared CDW are valued in any way, when the target set at EU level for 2020 was 70%. In this sense, it is estimated that 24% of CDW is deposited in landfills and 30% still represents uncontrolled dumping (Spanish_CDW_Recycling_Association, 2017). These data show the scenario that we are in and on which action must be taken to achieve the development of the construction sector within the circular economy.

The incessant increase in society's environmental awareness and culture, together with the increase in regulatory demands, make it the ideal time to implement the calculation of the carbon footprint (CF) as well as embedded energy (EE) in the construction sector, since in statistical terms, this sector is responsible for approximately 50% of the consumption of natural resources used, 40% of the energy consumed (including energy in use), 50% of the total waste generated and between 35-40% of the total CO2eq emissions, of which 10% are produced during construction and deconstruction processes and another 5% in maintenance tasks (UNEP, 2018).

The new European directive on the energy efficiency of buildings, tightens its objectives in pursuit of the elimination of fossil energy use in the housing stock by 2050 (Camporealle and Mercader-Moyano, 2019). To this end, it establishes as essential the energy renovation of the existing building stock, with an average annual renovation rate of 3% to be covered. Among the equations proposed by the directive, there are some innovative proposals towards the digitalization of energy systems as an opportunity to save energy during use (Directive_2018/844/UE, 2018) between others actions like eco-efficient proposal in the refurbishment for Social Housing.

The latest data from the European Commission on the circular economy states that avoiding waste production, promoting eco-design as well as the reuse of waste will provide EU companies with savings of around 8% of annual turnover and an annual reduction of greenhouse gas emissions of between 2 and 4% (EUROPEAN COMMISION, 2019).

In this sense, the LCA (Life Cycle Assessment) evaluates the environmental loads throughout the life cycle of a product, service or work. The International Standards

Organization (ISO) created the SC 5 sub-committee with the purpose of developing international standards to regulate the methodology for calculating universal environmental indicators. The study of the complete cycle includes the stages of extraction and processing of raw materials, production, transport and distribution, use, reuse and maintenance, recycling and final disposal.

LCA studies comply with the following standards: UNE-ISO 14040 Environmental Management. Life cycle analysis. Principles and reference framework (ISO_14040:, 2006) and UNE-ISO 14044 Environmental management. Life cycle analysis. Requirements and guidelines (ISO_14044:, 2006). Through this standardization of LCA calculation and considering the current boom in BIM (Building Information Modeling) technology, which allows all project information to be centralized in a digital information model, it becomes the ideal tool for implementing life cycle analysis from the design phase and thus laying the foundations for a model that allows the ideals of circular economy to take root in the building sector.

The main objective of this work is to increase the awareness of the responsible agents of the Architecture, Engineering and Construction sector about the direct and indirect environmental impact produced by their professional development, looking for the way to improve the skills and training of the professionals of the sector in the field of sustainable construction. It is therefore essential to begin to incorporate into the training of these professionals not only criteria based on the ideals of circular economy, but to provide them with tools that allow them to incorporate these ideals quickly and intuitively into the daily development of their professional activity. In this sense, the present study is developed, where the first advances are made for the creation of an interactive learning tool through BIM, with which it is possible to design and calculate a construction project, under criteria of circular economy.

For the inclusion of Life Cycle Assessment in BIM, we start from the methodology of quantification of environmental impact developed by the research group Arditec, to which the authors of this paper belong. This methodology for calculating the environmental impact based on the Ecological Footprint (EF) indicator (Solís-Guzmán, Martínez-Rocamora and Marrero, 2014), is part of the projects' budget and has been adapted to measure the complete life cycle of the building: urbanization (Marrero et al., 2017), use and maintenance (Martínez-Rocamora, Solís-Guzmán and Marrero, 2016, 2017), and rehabilitation or demolition (Alba-Rodríguez et al., 2017). They also study other indicators such as incorporated energy (EE) (Freire Guerrero and Marrero, 2015), carbon footprint (CF) (Solís-Guzmán, Martínez-Rocamora and Marrero, 2014; Freire Guerrero, Marrero Meléndez and Muñoz Martín, 2016; Solís-Guzmán et al., 2018a) and the water footprint (WF) (Ruiz-Pérez, Alba Rodríguez and Marrero, 2017; Ruiz-Pérez, Alba-Rodríguez and Marrero, 2019), as they are the most interesting indicators in the building sector thanks to the simplicity of their message and that they start from the quantification of resources carried out for the economic control of the projects.

The methodology is based on simple and accessible data processing, since the data come from open-access databases or information sources and can be consulted by anyone, anywhere in the world, such as LCA's generic databases (Martínez-Rocamora et al., 2016). The robustness of the methodology is since it is based on widely contrasted management tools such as the Construction Information Classification Systems (CICS).

In a review by Freire (Freire Guerrero and Marrero, 2015), the following stand out among others: MasterFormat (CSI/CSC, 1983), Uniformat (UniFormatTM. The Construction Specifications Institute, 1998), Standard Method of Measurement of Civil Engineering (Telford, 1991), CI / SfB (Jones, 1987) and the Uniclass (Omniclass, 2012). All these bases are proposed as an ideal tool for the accomplishment of the economic quantification or budgeting and as an integrating element since its system of decomposition and hierarchization makes possible to introduce a standardized process.

The basic concept in all of them is to divide a complex problem into simpler parts that can then be added, without overlap or repetition, to define the complete development of the projects. In Spain, the construction cost bases (CCB) have their own CICS and their scope is usually the geographical environment: The Institute of Construction Technology of Catalonia (ITeC, 2012), PRECIOCENTRO of Guadalajara (Official College of Quantity Surveyors, 2012), BPCM Madrid (Ministry of the Environment and Planning of the Territory, 2007), BDEU in the Basque Country (Department of Housing, 2012), BDC-IVE in Valencia (Ministry of Infrastructure, Territory and Environment, 2012), and the Andalusian Construction Costs Database (ACCD) (Marrero and Ramirez-De-Arellano, 2010). This last one is the one used in the development of the model; because it belongs to the geographical area in which the Arditec model has been developed and it presents a robust systematic classification, of simple and schematic application, which allows an estimation and quantification of basic resources, to which the different environmental indicators can be applied to obtain the environmental impact of the different building solutions.

Environmental indicators based on the LCA are recognized by the scientific community, and can be easily understood by society (Freire-Guerrero, Alba-Rodríguez and Marrero, 2019). In the present work, the Carbon Footprint (CF) indicator has been used, it is an indicator whose use is very extended, therefore there is a great amount of bibliographic revisions related to the use of the CF indicator in construction (Geng et al., 2017). Through the decomposition into basic resources (materials and machinery) provided by the ACCD's systematic classification of the different construction solutions, the ARDITEC model (Marrero, Rivero-Camacho and M Desirée Alba-Rodríguez, 2020) is applied, which translates this amount into terms of the impact produced by the resources during their life cycle, expressed through the CF indicator. The main objective is to be able to predict the impact that a project will generate at the design stage, by quantifying project quantities, identifying the materials that generate the greatest impact throughout their life cycle and replacing them with others that reduce their impact. Existing instruments for project cost control can be used as a tool for introducing sustainability considerations.

The sustainability of construction works, as well as the environmental performance and the calculation method, define the life cycle of the building according to the standard UNE-EN 15978 (UNE-EN_15978, 2012). The system boundaries on which this study focuses are the manufacturing phase of the construction materials and the waste they produce at the end of their life cycle.

2. METHODOLOGY

The methodological development is divided into two parts: the application of the Arditec methodology, which, starting from the breakdown carried out by the systematic classification of the budget, allows the environmental impacts of the basic resources to be quantified; and the implementation of this environmental information in the open BIM software, thus generating a tool for quantifying the reduction of environmental impact, so that the environmental impacts of the new solutions can be compared with traditional building solutions.

Firstly, constructive solutions are developed based on criteria of circular economy, respecting the technical and normative requirements demanded, to later evaluate the environmental viability of the solutions through the LCA methodology. From here, the BIM objects of the developed construction solutions are created. These BIM objects will be composed of the families of materials that define the construction systems developed, which are assigned the environmental impact calculated by the Arditec methodology and then integrated into the open BIM software through plug-in (Fig. 1).

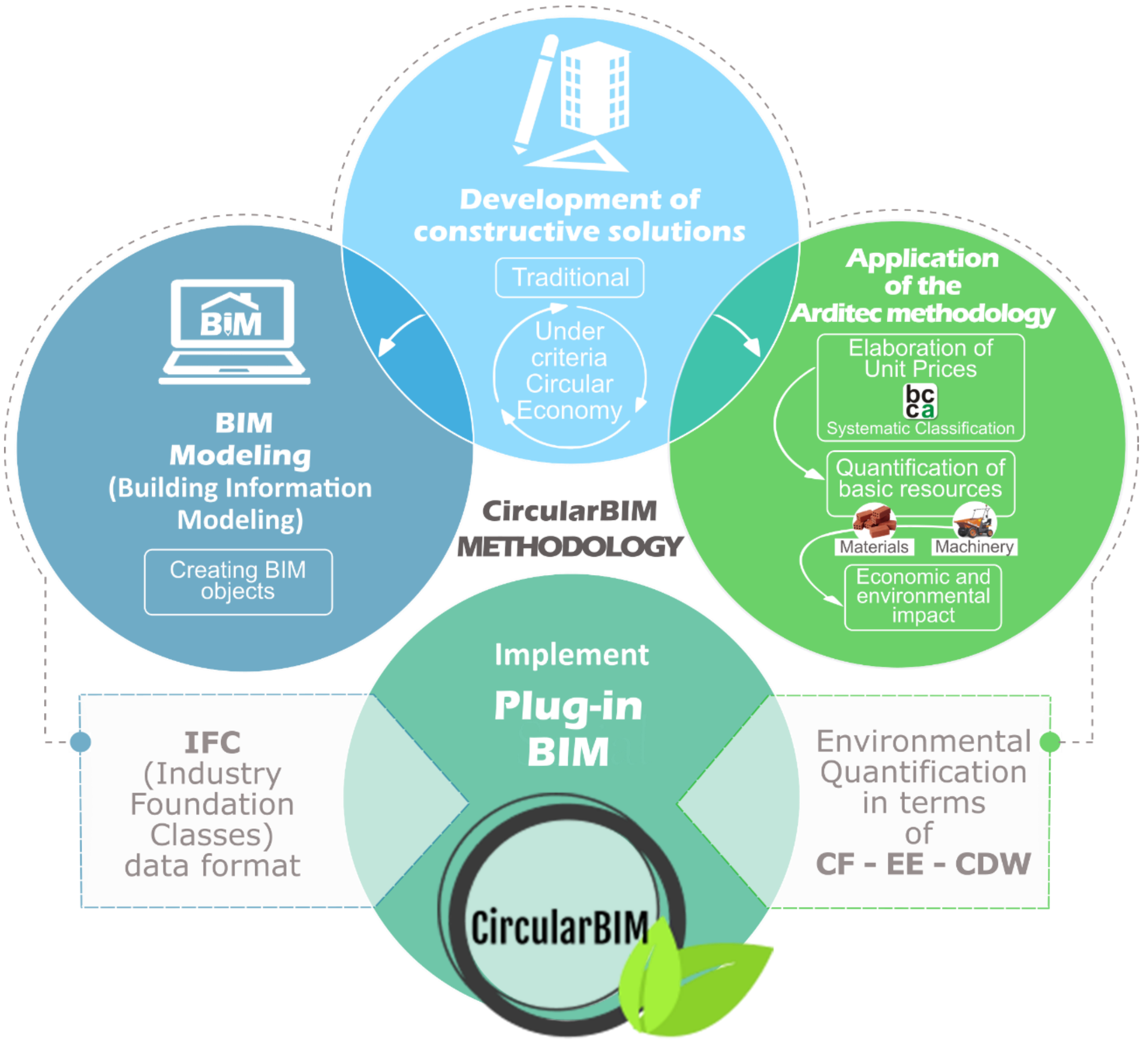

Fig. 1 Methodological flowchart. Source: USE.

2.1 Application of the Arditec methodology

2.1.1 Cost structure

Data and process automation are advances in Information Technology (IT) that provide great advantages in predictive analysis. As mentioned in the introduction to this work, the sector is dominated by construction information classification systems (CICS) as management tools, specifically the ACCD is used in this study (ACCD, 2017). Its Classification System of Systematic Information (Ramírez-de-Arellano-Agudo, 2010), is based on a hierarchical and arborescent structure with defined levels, where each group is divided into subgroups of homogeneous characteristics. This organization of work makes it easier to divide a complex system such as the work budget into simpler elements, i. e. materials, machinery and labour (Freire-Guerrero, Alba-Rodríguez and Marrero, 2019).

Consortium members: Universidad de Sevilla (USE), Asociación Empresarial de Investigación Centro Tecnológico del Mármol, Piedra y Materiales (CTM), CYPE SOFT SL (CYPE), Universitatea Transilvania din Brasov (UNITBv), Asociatia Romania Green Building Council (RoGBC), Centro Tecnologico da Ceramica e do Vidro (CTCV) and Universidade do Minho (UMinho).

Prices are expressed in terms of a given unit of measurement; but criteria must also be established so that, within the building project in question, the number of units that are subject to that price can be quantified. To this end, criteria are established to facilitate such measurement by means of appropriate compensation adjusted to the uses and customs of execution of these units (Alba-Rodríguez, 2016). The price-unit-of-work set is reinforced by establishing a single meaning for each duo in a rigid manner between the measurement criteria established for a given unit of work and its corresponding price; it is understood that if the criteria are modified, the price must be changed in turn, and common measurement criteria must be used for similar prices.

The concepts described above together constitute what is called a price epigraph, all prices have an and this is different for each element of the system. These elements are shown in the prices of ventilated facades in tables 3 and 4 of the section on construction solutions. All the above characteristics facilitate the incorporation of environmental cost based on the same hypotheses and contours defined in the calculation of economic cost.

2.1.2 Environmental calculation model

The environmental calculation model developed by the Arditec group to evaluate all the stages of the building's life cycle, allows the evaluation of different environmental indicators (Freire-Guerrero, Alba-Rodríguez and Marrero, 2019), (Marrero, Rivero-Camacho and M Desirée Alba-Rodríguez, 2020). In the present proposal, starting from the project's budget, the environmental impact of the materials is evaluated, which allows the identification of the families of materials that control the budget.

For this purpose, waste is quantified; as well as CF and EE indicators using international databases of LCAs of construction products and the Environmental Product Declarations (EPD) available on ECO-Platform (www. eco-platform. org/), a European platform for EPD programs in the construction sector that is established with the aim of an implementation of EN 15804 (ISO_15804:2012+A1:2013, 2012) with mutual recognition among the members.

A general analysis is made of the different concepts that make up an environmental indicator, in which the consumption of natural resources on the work is treated as an environmental cost.

Firstly, direct costs have been defined, which in traditional construction budgets correspond to machinery, labour and materials and in a similar way cause the direct use of resources on site through the expenditure of energy of the machinery used on site (fuel or electricity) and the consumption of construction materials (during their manufacture, transport and installation), as well as the generation of waste associated with this consumption of materials.

Quantification of waste:

Once the elements that make up the construction solution have been identified, the next step is to quantify the waste expected from them. The waste generating elements are identified by means of standardised classification and quantified by means of transformation coefficients (Solís-Guzmán *et al.*, 2009), by application of the equation (1):

$$QR_i = Q_i \cdot CR_i \cdot CC_i \cdot CT_i \qquad (1)$$

where: QRi is the amount of waste "i" generated by the material, Qi; CRi determines the amount of material that becomes waste; CCi changes the units of building components into units of waste; CTi is for the volume change of the material when it becomes waste. The system of units is the one used in the construction sector for each family of building materials, kg, m^3, m^2, or unit (u). The coefficients are calculated on the basis of the ACCD (ACCD, 2017) (see examples of coefficients Table 1).

Table 1 Examples of transformation coefficients (Marrero, Rivero-Camacho and M. Desirée Alba-Rodríguez, 2020)

Material		Origin	Destination		**Cr**	**Cc**	**Ct**
kg	Steel	losses	t	Steel	0.0	0.00	1.0
m^2	Ceramic brick	losses	m^3	Ceramic	0.0	0.01	1.3
t	Cement	losses	t	Cement	0.0	1.00	1.0
m^3	Concrete	losses	m^3	Concrete	0.1	1.00	1.1

Environmental Analysis:

Machinery

This is the impact of using machinery, specifically its direct energy consumption (both fuel and electrical energy), linking it to the power of its engine.

To obtain the fuel consumption, the "Machinery Manual" prepared by (SEOPAN, 2008) is used, where the technical data of different models and typologies of machines on the market are collected. Choosing the most unfavourable consumptions, the classified machinery is analysed, where a coefficient is applied to the power of each engine to obtain the litres of fuel consumed, differentiating whether the machine consumes diesel or petrol.

Once the litres of fuel consumed have been obtained, the coefficient is applied which indicates the amount of CO_2 generated by one litre of fuel (IDAE, 2011). To this data are applied those obtained from international LCA databases and their CF and EE are obtained.

A similar approach is followed for the consumption of the electrical machinery used on site, analysing the engine power and the hours of use, obtaining the total kWh consumed. The coefficient that indicates the CO_2 emissions generated for the production of one kWh of energy by the Spanish electrical system (REE, 2014), is applied to this data, i. e. , the GHG emissions, measured through the global warming potential (GWP) of the various gases emitted into the atmosphere by weighting the tons of gases emitted and transforming them into t of CO_2 equivalent.

Construction materials

The first step to be taken in order to obtain the environmental impact of each material consists of converting the original unit of measure of each basic price (m^3, m^2, meters, tons, thousands ...) to m^3, so that we can apply the density established in the support documents used, the Catalogue of Construction Solutions of the Technical Building Code (IETcc, 2010) and the Basic Document of Structural Safety of the Technical Building Code. Actions in the Building DB-SE AE (RD_314, 2006), to obtain the weight of each element.

Among the different LCA databases, the Ecoinvent database was chosen (Frischknecht *et al.*, 2005), implemented in Symapro and developed by the Swiss Center for Life Cycle Inventories, due to its transparency in the development of processes (reports, flowcharts, methodology...), consistency, references and standing out the fact that it merges data from several databases of the construction industry (Martínez-Rocamora *et al.*, 2016).

From this database, a series of "environmental families" have been obtained which will be responsible for assigning to each basic price their corresponding impact units according to their similarity.

From the life cycle inventory (LCI) for each of the materials, the emissions incorporated in construction materials have been analyzed, through the application of the IPCC 100 A methodology, which is used by the carbon footprint indicator since it isolates CO2 and other greenhouse gas (GHG) emissions from the LCI expressed in t CO_2 eq. /kg (Solís-Guzmán *et al.*, 2018b).

Figure 2 summarizes the methodology that combines the budget of the work with the environmental impact.

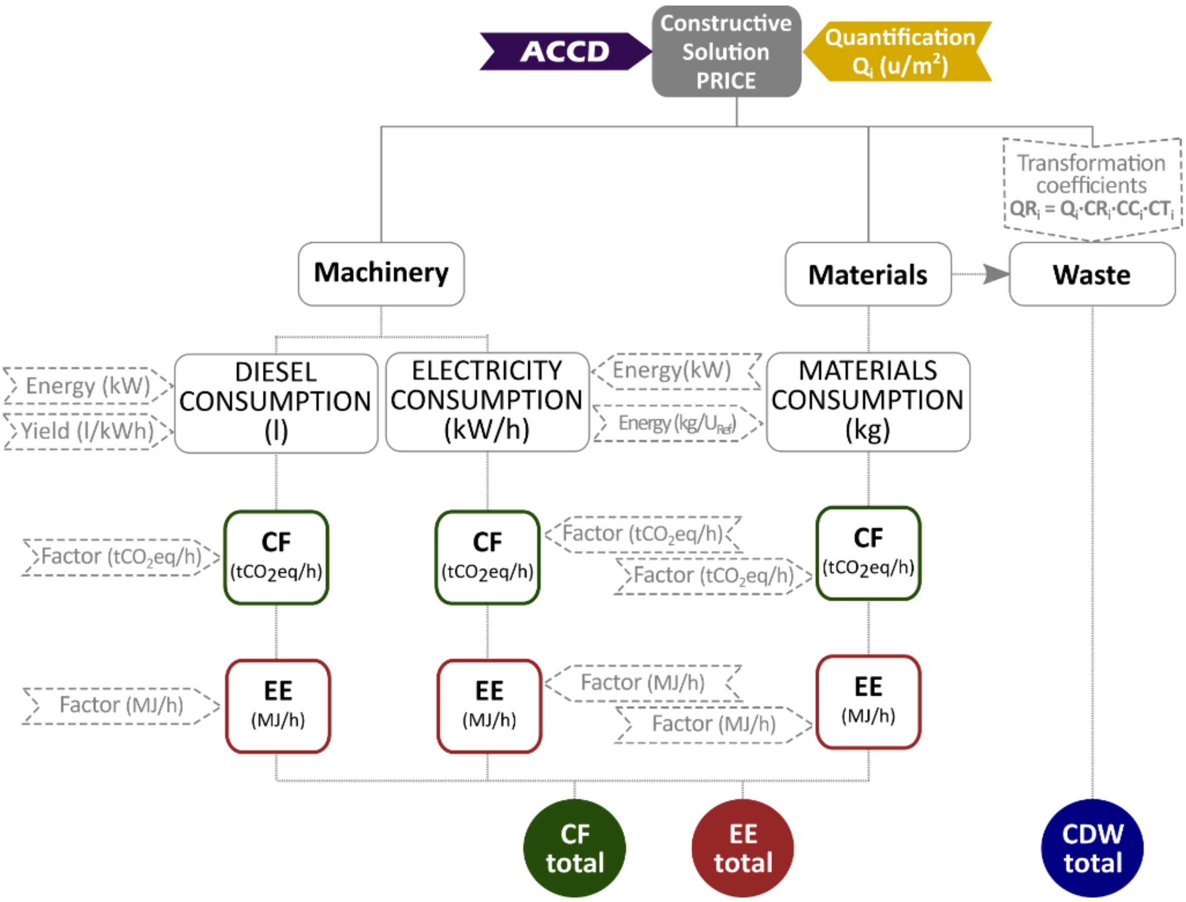

Fig. 2 Calculation methodology. Source: USE.

An analysis of the transport of the material is also carried out, establishing approximations of the distance covered by the means of transport, as in the previous section on machinery (Freire-Guerrero, Alba-Rodríguez and Marrero, 2019). The first thing to consider is the means of transport to be used, in our case it is by truck, whose capacity is defined in tons and average consumption of diesel, also considering the CO2 emissions for each litter of fuel consumed.

The second aspect to consider is the distance from the factory of each material to the work site; taking the following approximations: as our field of work corresponds to Andalusia, we consider that most of the materials are manufactured in that area, for which the distance corresponds to the average, 250 km. In the specific case of concrete, a maximum distance of 20 km will be considered, according to the considerations of EHE-08 (EHE-08, 2008).

With these data, we can obtain the tons of CO2 that would be involved in the transport of each material and/or waste; this figure will be reflected in the truck's capacity to obtain the value according to the kg of material transported, and this data can be applied directly to the weight of each basic price (Table 2).

Table 2 Data for calculating the impact of transport:

	Concrete	Other materials
Truck load capacity (kg)	24.0	2.0
Distance to factory (km)	20.0	250.0
Average diesel consumption (litros/100km)	26.0	26.0
Diesel emissions (tCO_2/litro)	2.6E-03	2.6E-03
Energy incorporated into diesel (MJ/litro)	57.7	57.7
Energy incorporated into electricity (MJ/kWh)	3.6	3.6

Implementation of environmental data in BIM

Once the model for quantifying environmental impact has been developed and given that the final objective is to automate environmental budgets through BIM tools, the next step will be to include the environmental information obtained through BIM. Given the incipient nature of the research, this section shows a brushstroke of how this task is to be tackled in the immediate future.

For the inclusion of this new environmental information in BIM, it is necessary to create this information in what is called IFC (Industry Foundation Classes) data format, whose particularity is that it allows the exchange of data from one information model to another without generating loss or distortion of data. It is an open, neutral format, not controlled by software producers, born to facilitate interoperability.

The IFC has been designed to produce all the information about the building throughout its life cycle, from the preliminary design to the execution and maintenance, including the different phases of design and planning. Most of the BIM resources currently available are focused on building and within this, the residential sector. For this reason, in the research being carried out and with the aim of making the most of the advantages offered by BIM, what we are trying to achieve is the expansion of its application in the different phases of the building's life cycle, going deeper into the benefits it can bring to sustainability, more specifically, how to incorporate the criteria of circular economy through BIM.

Thanks to IFC models, it is possible to create a virtual model of the building that is not a simple 3D representation, but a model that contains geometric information, materials, cost quantification, complex elements such as structures, installations, thermal characteristics, and even information related to the different phases of the building's life cycle.

The association of this additional information is achieved because the IFC structure is based on the semantics, relationships and properties of the modelled objects, created to describe the different components of the buildings (columns, beams, walls, slabs, etc.) being able to add specific properties to each object; quantification of costs through budgets, quantification of materials through measurements, and what is intended in this research, environmental quantification through the adhesion of Arditec methodology based on environmental indicators and LCA.

2.2. Constructive solutions

The methodology described above is applied to two construction solutions: one solution composed of materials traditionally used in construction, and this same solution modified with the incorporation of sustainable materials based on criteria of circular economy. The ventilated facade is the construction solution chosen as an example of development to show the progress of the proposed model. Complete construction descriptions of the solutions can be found in the price epigraph of tables 3 and 4, in correspondence with image 1 and 2.

Table 3 describes and breaks down the materials that make up the ventilated façade considered traditional (S01), table 4 shows the sustainable materials (S02) proposed to improve the environmental impact of the construction solution.

Table 3 Traditional ventilated facade price example (S01):

14FVL00001	**m^2**	**VENTILATED FACADE WITH NATURAL STONE OUTER CLADDING**
Main sheet of ventilated facade of perforated ceramic brick factory of 24x11,5x9 cm, received with M-5 industrial cement mortar. Thermal insulation consisting of mineral wool panel, according to UNE-EN 13162, 60 mm thick, thermal resistance 1. 75 m^2K/W, thermal conductivity 0. 034 W/(mK), placed between the uprights of the supporting structure, also p. p. of fastening, cutting and placement elements. Internal wall covering with 13 mm thick plaster plates for self-supporting plaster, placed on galvanised steel profiles with mechanical fixings, including staking out, cleaning, levelling, plumbing, making corners and repairing joints. Outer cladding made of machined Capri limestone plates, bush-hammered finish, 60x40x4 cm; installation using the continuous horizontal anchorage system on an adjustable aluminium alloy support substructure; substructure for supporting the external cladding using the horizontal anchorage system made of vertical extruded aluminium profiles with heat treatment; including screws and mechanical anchors in stainless steel, for fixing the substructure. Measure the executed surface.		

Code	Quantity	u	Description	Price	Cost (€)	CF (tCO_2eq.)	EE (MJ/h)	CDW (t/m^3)
TO02100	2.72	h	OFFICIAL 1ST	19.85	53.99	---	---	---

TA00200	2.52	h	SPECIALIST ASSISTANT	19.04	47.98	---	---	---
TP00100	0.50	h	SPECIAL PEON	18.80	9.45	---	---	---
MW00300	0.26	h	LIFTING PLATFORM	7.50	1.94	0.0108	177.3	---
06LHM00005	1.00	m^2	BRICK MASONRY	29.64	29.64	0.0717	832.4	264.26
09TPP00161	1.00	m^2	MINERAL WOOL INSULATION	11.14	10.14	0.0183	282.3	12.386
QP01100	1.00	m^2	ALUMINUM PROFILE	19.06	19.06	0.0231	372.4	1.93
10LWW90201	1.00	m^2	SELF-SUPPORTING COATING. PLASTER	18.18	18.18	0.0860	1457.4	19.97
RA05300	1.00	m^2	LIMESTONE PANELS 3 cm	37.87	37.87	0.0003	1.5	28.55
WW00400	2.00	u	SMALL MATERIAL	0.30	0.60	0.0003	5.3	0.00
				Total	229.85	0.2105	3128.7	327,09

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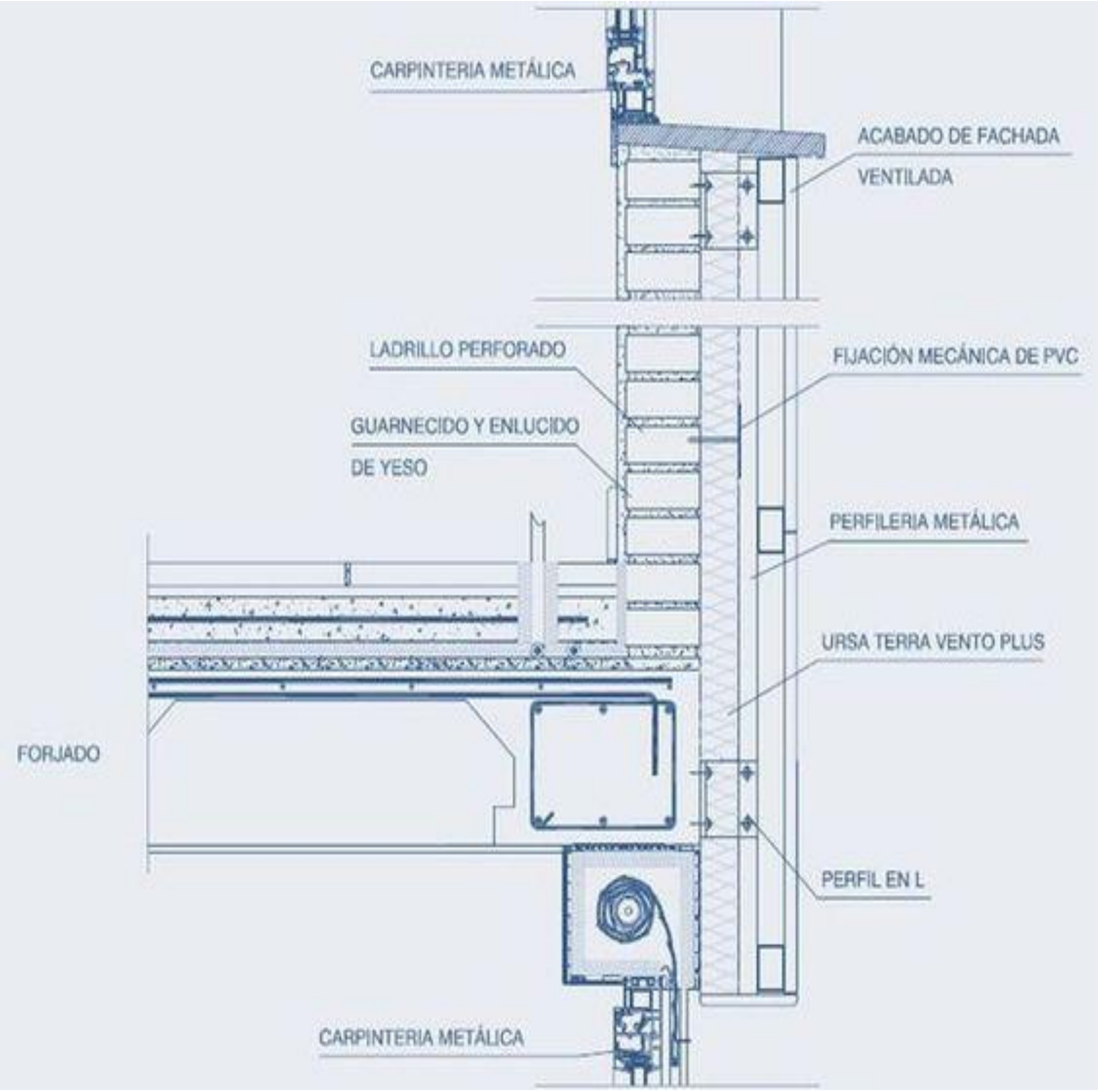

Image 1. Example of construction detail. Tradicional ventilated façade (S01).

Table 4 Sustainable ventilated facade price example (S02):

14FVL00002	m^2	VENTILATED FACADE WITH WOOD PANELING OUTER CLADDING
Main sheet of ventilated double hollow brick facade 24x11. 5x9 cm, received with M-5 industrial cement mortar. Wall insulation with 110 kg/m^3 density conglomerate cork sheets 60 mm thick, placed on flat surfaces, including cutting and laying and complementary material. Interior wall cladding with wooden plates for self-supporting wall tiling, placed on wooden profiles, including staking out, cleaning, levelling, making corners and repairing joints. Exterior coating of natural wood composite panels for exteriors, consisting of a body of high-density bakelite, coated with natural wood		

veneer treated with synthetic resins that provide greater durability, protection from solar radiation, atmospheric agents, dirt and chemical attacks (anti-graffiti). It is part of a construction kit for the cladding of ventilated facades formed by natural wood panels and their corresponding substructure. Due to their high resistance, they do not require the usual maintenance of other outdoor woods. Materials with more than 8% of raw material of recycled origin and ecolabel III. Measure the executed surface.

Code	Quantity	u	Description	Price	Cost (€)	CF (tCO_2eq.)	EE (MJ/h)	CDW (t/m^3)
TO02100	2.72	h	OFFICIAL 1ST	19.85	52.99	---	---	---
TA00200	2.52	h	SPECIALIST ASSISTANT	19.04	47.98	---	---	---
TP00100	0.50	h	SPECIAL PEON	18.90	9.45	---	---	---
MW00300	0.26	h	LIFTING PLATFORM	7.50	1.94	0.0108	177.3	---
06LHM00005	1.00	m^2	BRICK MASONRY	29.64	29.64	0.0717	832.4	264.26
10LWW90202	1.00	m^2	CORK PANELS INSULATION	14.44	14.44	-0.0040	354.1	6.71
10LWW90300	1.00	m^2	SELF-SUPPORTING COATING. WOODEN PANELS	19.51	19.51	0.0388	967.2	15.22
RA00200	1.01	m^2	OUTER COATING. WOODEN PANELS	83.97	83.97	0.0250	684.8	13.08
WW00400	2.00	u	SMALL MATERIAL	0.30	0.60	0.0003	5.3	0.00
				Total	262.36	0.1427	3021.2	299.26

The materials of the S02 solution have been selected under environmental criteria, specifically materials that, in addition to meeting the technical conditions required for their function within the construction solution, have eco-label III (EPD) and have a percentage of recycled material in their composition, thus certified in their corresponding eco-label. In this way we ensure that we are incorporating materials produced under criteria of circular economy, as well as being certain that these materials are available on the market.

Image 2. Example of construction detail. Sustainable Ventilated Facade (S02).

3. DISCUSSION OF RESULTS

After applying the methodology described, the economic cost (euros) and the environmental impact in terms of Carbon Footprint (CF), Embedded Energy (EE) and Waste (CDW), of each construction solution is obtained. Firstly, attention is focused on the total results, both economic and environmental, of both ventilated facade solutions, represented graphically in Figure 3.

It can be seen how the S01 solution, made up of materials traditionally used in construction, presents a lower economic cost than the S02 solution that incorporates materials with environmental and recyclability criteria. However, when comparing the economic cost with the environmental impact, it can be seen that the environmental cost of the S02 solution is lower in any of the three indicators (CF, EE and CDW) used in the analysis.

It is interesting to make a comparative analysis of Figure 3, through the economic and environmental breakdown by materials, where it can be seen that in both ventilated facade solutions, the highest economic cost falls on the elements that make up the outer leaf of the enclosure, the S01 solution being 8% more economical. When comparing the environmental results in terms of CF and EE of these same elements, it can be seen that the S01 solution presents an environmental impact between 7% and 11% less.

This is due to the fact that the exterior sheet cladding of the ventilated facade of the original S01 solution is composed of natural stone, whose transformation process requires very low incorporated energy and as a consequence, low CO_2 emissions, while in the S02 solution the cladding material is made of special wood for exteriors treated with bakelite and synthetic resins that require more incorporated energy in their production processes.

In contrast, when comparing the CDW generated by both solutions, it can be seen that with the S02 solution, the generation of CDW is reduced by around 5%, thanks to the fact that the coating plates of this solution have a high percentage of recyclability and contain more than 8% of raw material of recycled origin, certified through ecolabel type III.

Continuing with the analysis of the results by materials, it is worth noting the comparison between the insulation materials used in the construction solutions, where the CF of the insulation materials of the S02 solution stands out, which is represented in the graph in negative terms.

This is due to the fact that the cork used as an insulating material in the S02 solution during its manufacturing process produces fewer emissions than the CO2 sequestration carried out by cork oak forests, the tree from which the cork raw material comes, in its life cycle analysis, which translates into a negative balance of the carbon footprint.

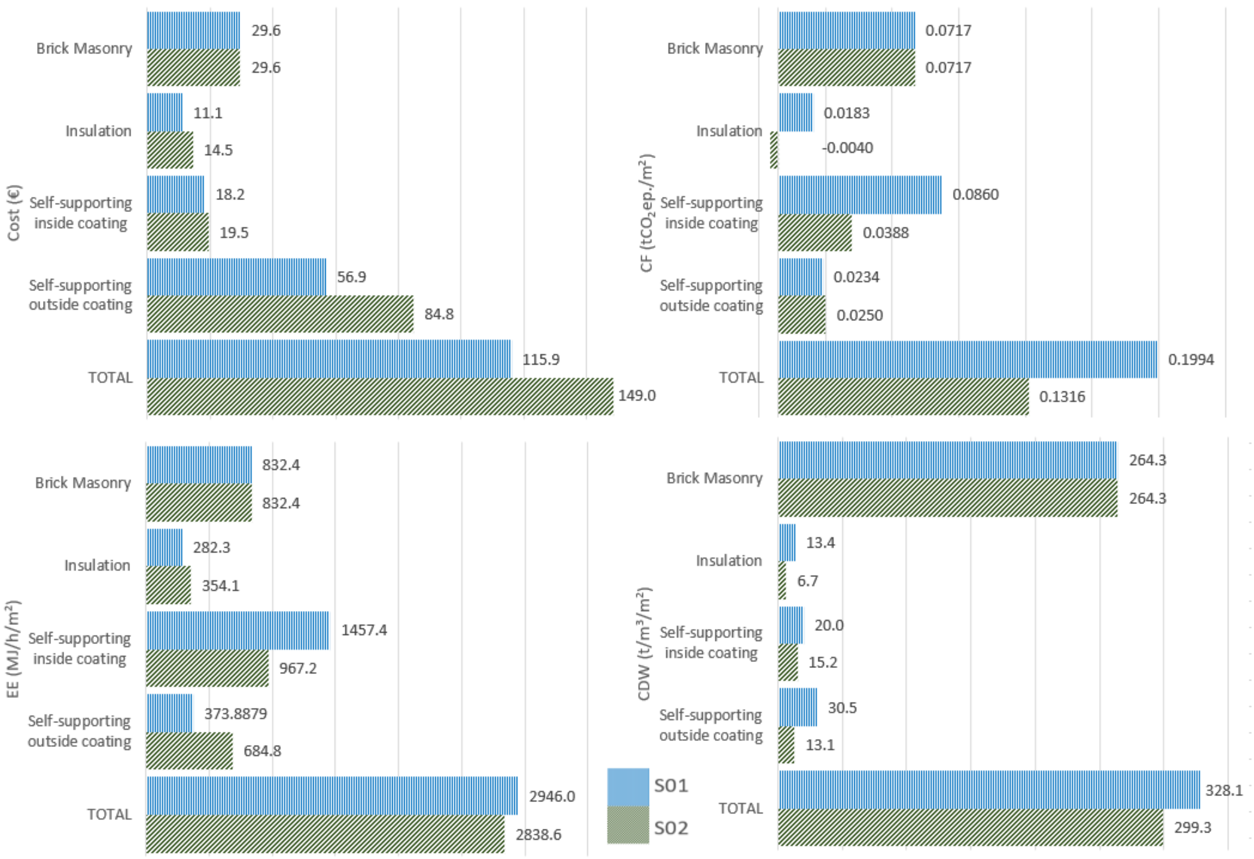

Fig. 3 Economic and environmental comparison by material of the S01 and S02 ventilated facade solutions.

The material that produces the greatest environmental impact of the solution should be highlighted in two of the indicators used in the analysis (CF, EE), namely the laminated gypsum boards, the lining material of the interior plasterwork that makes up the S01 solution. This element represents around 43% of the CF and 49% of the EE of the constructive solution, due to the high impact it generates from extraction as a raw material, through its entire life cycle to its generation as waste, since this material has few possibilities for reuse and recycling, so it is far from the criteria of circular economy.

In the S02 solution, this material is replaced by wood sheets made from recycled wood, which manages to reduce the CF of the solution by around 55% and the EE by 34%, in addition to contributing to the reuse and recycling objectives pursued by the circular economy

To conclude the analysis, we focus on the indicator referred to the CDW, which allows us to glimpse the amount of waste generated by the materials that make up the different construction solutions and thus analyze the possibility of recirculation and recyclability of such waste. According to the results obtained, all the elements of the S02 solution have a lower waste generation than the elements that make up the S01 solution. Of this analysis, the outer leaf stands out, generating 53% less waste in the S02 solution than in the S01 solution. This is due to the potential use of wood materials that make up the outer sheet of the S02 solution. In the analysis of the results of this indicator, it is necessary to consider, in addition to the generation of waste from the different elements, the percentage of recyclability of such waste.

Given that the ventilated facade solutions analysed in this work are characterised by their ability to be dismantled, i. e. , that at the end of their useful life it is possible to dismantle the different materials that make up each element, the percentage of recyclability of these is increased. Specifically in the case of solution S01, considering the total weight of the construction solution (440. 38 kg), the recyclability of the total of its components is around 74%, while solution S02 (total weight 412. 56 kg) presents a recyclability of 73%.

4. CONCLUSIONS

Construction cost databases are traditionally used in the sector to generate and control budgets. These databases allow the precise determination of the resources used in a building project; moreover, thanks to their internal structure and systematic classification, it is possible to reliably include environmental indicators for the parallel calculation of the project's environmental cost. This becomes an opportunity to introduce environmental awareness and control of the project through these cost bases, widely integrated by the agents of the sector for the economic control of the projects.

Taking advantage of the current boom in BIM technology, which allows all the project information to be centralized in a digital information model, they make it the ideal tool for promoting this environmental awareness from project budgets.

Including this calculation of the environmental impact through the different environmental indicators (CF, EE and CDW), the tool that is proposed allows to quantify the reduction of the environmental impact generated by the projects, so that the environmental impacts of the new solutions can be compared with traditional constructive solutions.

A sample of this statement is extracted from the results obtained from the application of the methodology described above on the two construction solutions analyzed, observing that the solution composed of traditional materials presents a lower economic cost than the solution that incorporates materials with environmental and recyclability criteria, in contrast with the environmental results, where it is appreciated that the solution that incorporates environmental criteria presents less impact for any of the three indicators (CF, EE and CDW) used in the analysis.

The detailed breakdown by construction elements that is possible due to the internal structure and systematic classification of the cost bases, allows the identification of those materials of the construction solutions that generate a greater environmental impact and thus to propose a substitution alternative that reduces this impact. In the specific case of the solutions analyzed in this work, the lining material of the interior plaster (laminated plaster boards) has been identified as the material that produces the greatest environmental impact, representing around 43% of the CF and 49% of the EE of the construction solution.

This allows to propose and quantify as an alternative to replace this element with another that generates less impact, specifically in this case it is considered to replace it with wood sheets made from recycled wood, which manages to reduce the CF of the solution by around 55% and the EE by 34%, in addition to contributing to the objectives of reuse and recycling that the circular economy pursues.

The aim of the tool proposed in this paper is to incorporate the calculation methodology described in building projects using BIM technologies. For this purpose, after including the characteristics of the specific project and the geometric definition of its BIM objects, the environmental impacts of each previously defined construction solution can be calculated and represented by means of indicators.

The information can be added to the BIM model through plug-ins, inserted directly into the BIM software or by sending the BIM information to the environmental assessment tools. As it is an open resource, it will be possible to access the software free of charge and obtain construction techniques that facilitate the reuse of materials used in construction.

In conclusion, the idea is to unify BIM technology and the techniques of revaluation and reuse of construction materials based on the ideals of circular economy, thus creating a useful tool for both students and professionals in the Architecture, Engineering and Construction industry.

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