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A Work Breakdown Structure for Estimating Building Life Cycle Cost Aligned with Sustainable Assessment—Application to Functional Costs

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Abstract: The tools used for budgeting in the building design phase are still insufficient to address the life cycle of the building in terms of environmental and cost impacts. The main objective of this research is to define a model for extending existing cost databases to accommodate life cycle sustainability assessment. For this, current classification systems are reviewed and a case study has been analysed using the new approach. To this end, a new system of classification of construction information is proposed for the evaluation of early design costs, when data are scarce and the only information available refers to the gross interior area and the plot. The classification organizes the costs in a similar way to the sustainability assessment in EN-15643. A subcategory has been added for revenue, developer costs, and taxes at all stages of the lifecycle. The resulting classification is applied to the functional elements of a secondary school project. In the case study, construction costs represent 21% while the use stage accounts for 72% in a 100-year lifespan. The results show that, starting from generic cost bases, more complex costs and functional costs can be defined at different stages of the life cycle and adjusted to sustainability assessment standards.

Keywords: building; life cycle cost; functional costs; early design costs; construction information classification system; work breakdown structure; sustainability

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1. Introduction

It has become essential for the construction sector to act in order to achieve a sustainable economic model, since it represents 13% of the world's GDP [1], 5.4% in the European Union, and 5.7% in Spain [2]. Furthermore, buildings have a long life cycle, and hence they have an impact, not only when they are first built, but throughout their useful life. For example, the operating costs of buildings can account for more than 40% of their total expenses [3]. This takes on special significance in the construction of public works, since their costs represent a long-term commitment of public funds [4]. Life cycle cost (LCC) must be addressed in order to analyse the economic sustainability of construction.

In 2014, the European Union introduced the LCC concept in the evaluation of public tenders through Directive 2014/24/EU [5]. The directive contains criteria for awarding public contracts that include economic, environmental, and social aspects, and places emphasis on the LCC indicator, which makes it possible to control the cost of the construction of the building, and of all the subsequent stages of the life cycle: use, maintenance, and end of life. This indicator is used, among others, in the sustainability assessment of Level(s) [6] and BREEAM [7].

The LCC indicator is not a new concept; it was first applied in the mid-20th century in the military industry [8]. In the case of building construction, this requires the adaptation of traditional construction cost databases, and hence it is necessary to clearly define exactly to what the LCC refers. Currently, the most prominent standards are the ISO 15686-5 standard [9] and the EN-15643 standard [10] (Figure 1). The most notable difference between the two is that for the former, the LCC concept only includes the costs related to buildings from their construction to the end of their life (blue box) and introduces another concept, whole life cycle cost (WLC) where pre-construction costs, revenues and externalities are added. This double definition can understandably lead to major confusion [11], and it is therefore always necessary to declare under which regulations the calculation of the indicator is to be carried out. In the European standard, as shown in Figure 1 on the right-hand side, the LCC concept already includes pre-construction costs and revenues.

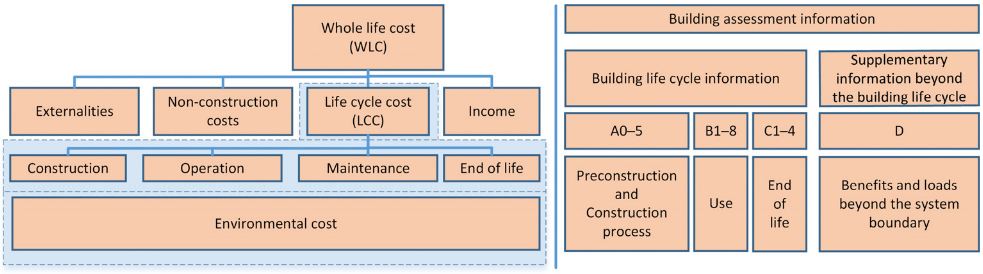

Figure 1. Categories of overall life cycle cost: on the left-hand side according to ISO 15686-5, and, on the right-hand side, EN-15643. In the blue box, the life cycle cost.

Research on LCC has received increased interest in recent decades, as shown by Goh et al. [11]. They reviewed 45 works related to the LCC calculation of conventional and green buildings. And Islam et al. [12] reviewed over 50 works which advance in simultaneously evaluating LCC and LCA in the construction of residential buildings. Among more recent proposals can be found a systematic classification through a work breakdown structure (WBS) that considers all the operating costs of a building throughout its life cycle, including its water and energy consumption, through a unified framework that allows the flow of design and construction information in the correct management of the building. For this, the Omniclass and Masterformat classifications are combined. This WBS-based framework aims to cover the entire life cycle of an asset to provide a unified classification system for asset inventory [13].

In the particular case of the study of building structure solutions, Abou et al. propose LCC assessment for design selection. They studied reinforced concrete, structural steel, and cold-formed steel frames and compared the results. The framework is developed in accordance with the relevant guidelines for LCA and sustainability and is intended to support decision-making at the design stage. They combine LCC and LCA simultaneously in the analysis of the structure's life cycle [14]. In a more general way, LCC is employed in the creation of a selection tool with design variants in building construction [15]. They developed an LCC calculation tool in Excel.v2403 that includes individual variants of building designs with different input parameters. It analyses the components or equipment that have the greatest impact on total LCC. It also assesses the long-term economic efficiency of proposed residential buildings. The calculation of the costs of servicing, maintenance and renovation of the building elements is determined for each element. This is achieved with data on their service life, maintenance intensity, service intensity, and operating costs. Finally, the calculation of the costs consists of a percentage rate based on the acquisition costs.

But there are still limitations in the development and validation of LCC estimation. Barriers have been identified such as "varying definitions of LCC calculation methodologies; the availability and standards of data sources, in particular, the misalignment of coding systems for identification and classification of components at various levels of development, proprietary ownership of data, lack of knowledge and skills in team members to produce and/or utilize data sources, and limitations of software" [16].

In the particular case of Spain, The Directive 2014/24/EU has been consolidated into national legislation by means of the Law on Public Procurement [17]. Prior to the publication of this European directive, the legislation on the contracting of public works only contemplated the evaluation of the construction costs of new buildings. To this end, public administrations regularly publish their construction cost databases, which facilitates the preparation of budgets for new buildings. Costs are calculated per work unit, which is defined as "a construction element formed of basic or auxiliary elements which is carried out by a group of specialists" [18], as required by the public procurement legislation [17]. Defining a construction project's scope and establishing its WBS are the first steps to estimating its costs. Their aims are to classify and code work, however, significant overlapping still takes place, as per surveys performed in the sector [19]. Construction costs and, to a lesser extent, end-of-life costs are usually the most commonly estimated, although, in general, information regarding the costs of the pre-construction use, maintenance, and end-of-life stages remains scarce and/or unreliable [20]. As a result, existing cost databases are insufficiently prepared to deal with the assessment of LCC.

This research addresses the creation of a Construction Information Classification System (CICS) for the calculation of building LCC in the early design stage that is adapted to international models of sustainability analysis in buildings. To this end, national and international systems are reviewed and compared. From their combination, the new classification organises the information and construction types. This enables the calculation of the LCC required by the legislation on contracts in the public sector [17].

2. State of the Art

2.1. Analysis of Existing CICS

Faced with the challenge of creating a new database of construction information adapted to the calculation of LCC, it is necessary to select the most suitable CICSs. These systems constitute fundamental tools for cost analysis which can be used in both the professional and scientific fields. The international standard ISO-12006-2 [21] organises and classifies the basic concepts. In addition to cost assessment, if the classification is associated with the standards for the calculation of environmental sustainability it would be possible to carry out economic and environmental calculations with the same system structure [3,22,23].

Afsari and Eastman [24] compared different CICSs according to their purposes and properties, frameworks, grouping principles, and organisation of classification models. Based on their criteria and adding new elements of evaluation such as scope of use, coding, life cycle, and scope boundaries, a comparison is carried out of the main international systems, focusing, in particular, on the Andalusia region (see Table 1). The criteria are defined below:

(1) Scope of use: Sets the geographic scale of use for which the classification model is created.
(2) Purpose of the classification model: Initial step in the classification of objects. Identifies the interest for which the classification model has been made [25].
(3) Conceptual framework: The framework on which the classification model is built. Related to higher-level information classification models.
(4) Grouping principle: This defines whether the grouping is single or multiple, related to the vision of grouping and classifying objects [24], by adding whether the classification model is itself a conceptual framework. ISO 12006-2 [21] classification is employed: resources, processes, results, and properties.
(5) Organisation: This defines the item classification organisation in order to distinguish items within a collection [25]. Specifically, these are the information levels of development.
(6) Coding: This establishes the coding type, numeric or alphanumeric, of the classification model.
(7) Life cycle: This defines the temporal boundaries of the information incorporated into the classification model according to the stages of the building's life cycle.
(8) Scope boundaries: This establishes the physical boundaries of the information incorporated into the classification model. It determines whether the information is

about the endogenous and/or exogenous costs of building elements. Endogenous costs refer to the costs related directly to the construction site, while exogenous costs are those necessary for the completion of the project but take place away from the construction site.

Table 1. Comparison of Level 0 and Level 1 classification models. The columns stand for (1) scope of use, (2) purpose of the classification model, (3) conceptual framework, (4) grouping principle, (5) organisation, (6) coding, (7) life cycle, and (8) scope boundaries.

Level 0: Conceptual framework								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
ISO	Int	Classification per class of objects in the building (objects = resources, processes, result, or property)	General frame	Mult	12 classification proposals grouped into resources, processes, results, and building properties	None	Yes	En. and Ex.
Level 1: Multiple Classes								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
OMC	NA	Organisation and classification of all the information regarding the products of the objects in the building environment in their life cycle	ISO 12006-2 ISO 12006-3 [26] MasterFormat, Uniformat, EPIC	Mult	15 tables representing different visions of building	Num	Yes	En. and Ex.
UNC	UK	Classification system for all aspects of design and construction process	ISO 12006-2, SfB, CAWS, EPIC, CESMM	Mult	11 tables	Alpha	No	En. and Ex.
EN	EU	Framework for the evaluation of the sustainability of buildings and civil works	Compatible with ISO 12006-2	Mult	Unique classification system	Alpha	Yes	En. and Ex.
Level 2: Single Class								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
ICMS	Int	International Cost Classification System	NRM [27] ISO 12006-2	U	Three classification levels, cost category, cost group, cost sub-group	Num	Yes	En. and Ex.
CEEC	EU	Exchange of international construction cost information	Construction Professionals	U	One level	Num	Yes	En. and Ex.
UNI	NA	Organisation of the information around the functional elements of the building. Mainly used for cost estimation	Construction professionals. WTO.	U	4 hierarchical levels of development	Num	No	En.
MAS	NA	List for the organisation of executed units of work, requirements, products and activities. Mainly used in bids and specifications of work units.	Construction Industry Uses	U	4 hierarchical levels	Num	No	En.
ACCD	S	Work units for execution projects	Spanish Public Procurement Legislation	U	Three cost tables (basics-2 levels, auxiliary-3 levels, and unit costs-4 levels)	Alpha	No	En.

Abbreviations: Omniclass (OMC), International Cost Management Standard (ICMS), Conseil Européen des Economistes de la Construction (CEEC), Uniclass (UNC), Masterformat (MAS), New Rules of Measurement (NRM), Andalusian Construction Cost Database (ACCD), International (Int), North America (NA), United Kingdom (UK), International (Int), European Union (EU), Spain (S), multiple (mult), single (U), numeric (Num), alphanumeric (Alph), endogenous (En.), and exogenous (Ex.).

Table 1 analyses the most representative international and national CICSs and classifies them according to the levels indicated in the ISO 12006-2 standard, which aims to establish a framework for the classification of building information from the point of view of object-oriented programming. At Level 0, there are systems that contemplate a conceptual framework of classification. Level 1 includes those that contemplate multiple types of classifications, such as resources, processes, results, and properties. Lastly, Level 2 includes

CICSs that have only one classification type (see Figure 2). A particular case is the EN-15643 standard, since it is a conceptual framework that contains the assessment of the environmental, social, and economic sustainability of construction with a single information structure throughout the life cycle. The standard development at the building level is currently pending [10].

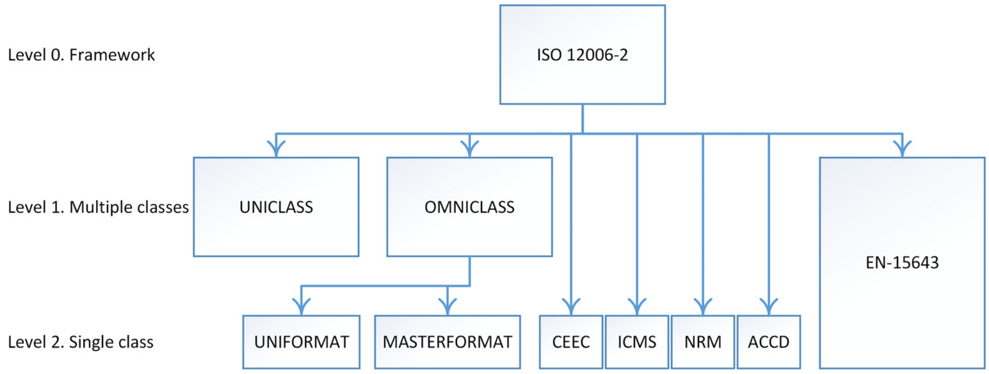

Figure 2. Hierarchical Structure of Classification Models. Abbreviations: Uniclass (UNC), Omniclass (OMC), Conseil Européen des Economistes de la Construction (CEEC), International Cost Management Standard (ICMS), New Rules of Measurement (NRM), and Andalusian Construction Cost Database (ACCD).

In North America, two main classifications have been developed, Masterformat and Uniformat. Both are conducted by the Construction Specifications Institute (CSI) and the Construction Specification Canada Institute [28]. Masterformat is the most widely used standard for construction information classification, mainly in the form of the product and technical information classification of building work units. Uniformat is largely used for the estimation of the functional element costs of buildings. In an attempt to unify concepts, CSI and CSC have supported, since 2006, the Omniclass classification, which structures information in a common format across several tables. Thus, the Uniformat and Masterformat classifications are represented by the Omniclass information in Tables 21 and 22, respectively. The Uniformat, Masterformat, and Omniclass classifications hold particular importance since they are supported by the BIM-IFC building models [29].

In Great Britain, the Committee of Construction Project Information (CPIc) created Uniclass in 1997, whose most recent version is from 2015, with the aim of creating a classification system for all aspects of design and the construction process by integrating the Construction Index/Samarbetskommitten for Byggnadsfragor tables (CI/SfB), the Common Arrangement of Work Sections for Buildings Works (CAWS), the Electronic Product Information Cooperation (EPIC), and the Civil Engineering Standard Method of Measurement (CESMM) [24]. Uniclass is currently updated by the Royal Institute of British Architects (RIBA) on the NBS professional platform [30].

At the European level, the Conseil Européen des Economistes de la Construction (CEEC) created the Code of Measurement for Cost Planning [31]. The council implements a classification of building costs that can be integrated with other national classifications and can be employed to make international cost comparisons at the management level [32]. This classification is used in European research projects, such as Life Cycle Costing and Cravezero [33].

Since 2017, the International Construction Measurement Standards Coalition (ICMSC) has published the International Construction Measurement Standard (ICMS). This standard is based on the New Rules of Measurement (NRM), developed by the Royal Institution of Chartered Surveyors (RICS), and aims to standardise the classification of construction costs at all levels from local to international in order to compare costs in a consistent and transparent way [34]. The standard supports life cycle cost from the 2019 release.

In Spain, there have been several CICSs developed over the last 40 years with a unifying exchange format called .bc3 [35]. This format is reviewed and updated periodically, and the Spanish software uses public and private tools for the creation of project budgets. These include ITEC in Catalonia, CYPE in Alicante, Construction Cost Database of the Community of Madrid, BDC-IVE in Valencia, BDEU in the Basque Country, PRECIOCENTRO in Guadalajara, and the Construction Cost Database of Andalusia [23].

In the particular case of this work, its geographical focus is Andalusia, Spain. The CICS of the Andalusian Construction Cost Database (ACCD) is used as a reference [36]. The database is employed for the cost estimation of architectural projects and it is based on the definition of work unit costs. Its hierarchical costs division is harmonised with the cost structure proposed by Spanish public procurement legislation. This meets the most commonly used decomposition criteria internationally, where the main divisions of WBS for building projects are elements, work sections, physical location, and auxiliary means of construction [37].

2.2. Coding of the CICSs

The coding of a cost database is a key issue in the identification and organisation of the information in an unambiguous way and brings simplicity to the information processing. The use of letters, digits, or combinations thereof has both advantages and disadvantages. Alphabetic characters enable the same number of sub-divisions as the number of letters in the alphabet of each language; for example, in Spanish it would admit 27 sub-divisions. On the other hand, numeric characters only support 10 sub-divisions at each level. Another advantage of letters with respect to digits is that they allow the first letter of each title to be associated with a certain concept but are only identifiable in the language of the titles, and therefore would not provide an intuitive universal coding system.

Table 2 summarises the coding employed by the CICSs reviewed: Uniclass [30], ACCD [36], CEEC [31], EN-15643 [10], and the ICMS [34]. All have alphanumeric classifications, except for the ICMS, which contains numeric characters exclusively.

Table 2. Comparison of cost classifications.

Name	Code
Uniclass	ZZ-NN-NN-NN-NN
ACCD	NN-Z-Z-Z-NNNNN
EN-15643	Z-N
CEEC	Z
ICMS	NN-N-NN-NNN

N is for numeric characters and Z is for alphabetic characters.

3. Methodology

The main objective of this study is to create a CICS which organises costs throughout the life cycle of buildings, and a model to evaluate costs at a pre-design stage when design data are scarce and only approximate information is available on the needs of the building and its characteristics.

First, the new CICS should contain a classification of the stages or categories of the life cycle. To this end, it is proposed that the classification considers the ISO 12006-2 normative framework [21], the EN-15643 standard [10], since it is a life cycle structure, and the ISO classification [9]. The separation of LCC and CGCV concepts in the ISO standard is unnecessary, however, since pre-construction externalities, revenues, and costs can all be included as sub-categories within each stage of the life cycle.

Secondly, it is essential to establish a structured definition of a building divided into elements that can be quantified. The division element of buildings that is considered most appropriate for the pre-design phase is the functional unit cost, understood as the cost of the construction element which has a complete function within the project, which is formed by a set of basic, auxiliary, and unitary elements that constitute a construction whole [18].

Each functional element is the consequence of the characteristics, needs, and uses that the building is going to have. Therefore, the cost database will be composed of functional elements of the building, with their corresponding costs of construction, consumption, maintenance, repairs, replacements, and end of life.

Regarding the sources of information, it should be borne in mind that the cost information retains its reliability and quality because the costs of functional elements are an aggregation of the costs of basic elements, auxiliaries, and work units, all of which are sufficiently contrasted since they are already part of the existing construction cost databases in use in Spain. In this work, the costs of the basic elements, auxiliaries, and work units are those included in the ACCD, since the final objective is their application in Andalusia (Spain) [36]. Two types of functional elements are used: functional cells and functional areas. Functional cells are defined as a combination of constructive elements that give shape to a homogeneous functional space, defined by boundaries that guarantee that there are no gaps or overlaps, such as a teaching classroom. Functional areas are an aggregate of cells and are defined as the combination of constructive elements that give shape to a set of homogeneous functional spaces, defined by boundaries that guarantee that there are no gaps or overlaps, such as a classroom building [18].

Thirdly, it is necessary for each functional element to be defined in the context of a building typology, since the technical characteristics can vary considerably. In this respect, the classification of building typologies proposed by the cadastral regulations of Spain has been selected as a reference [38]. Figure 3 provides an outline of the procedure for the creation of the cost database.

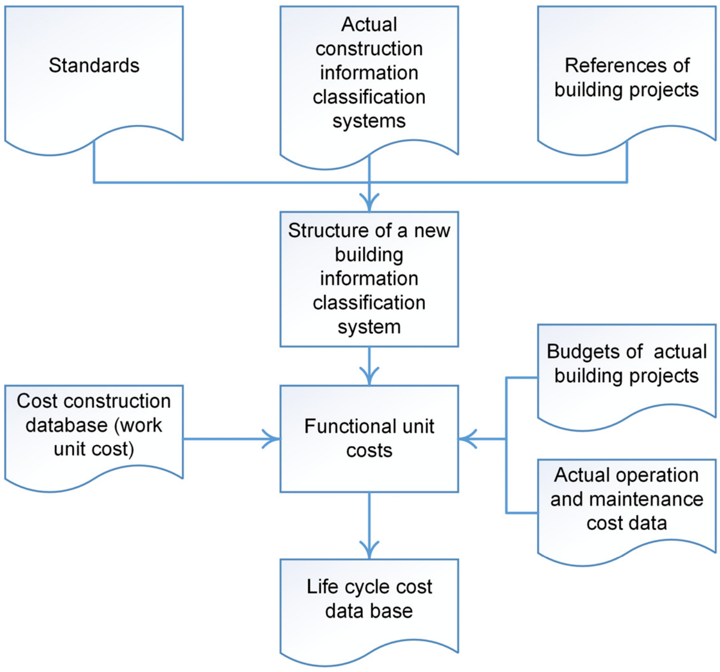

Figure 3. Methodological schema for the creation of a CICS for public works projects in Spain.

For the creation of functional costs, the case study of a state secondary school building located in Andalusia has been chosen. Based on the tendered projects with this typology, the design regulations of these buildings, and on the actual costs of supplies, the functional costs that comprise the buildings are defined. The projects and design regulations in the region provide the ground floor area that is usually required in the design of these buildings, as well as the quantity surveying of similar previous projects. For data on supplies and other expenditures, information is provided by the regional government.

3.1. The Structure of the New Classification System

Firstly, the new structure takes into consideration the Uniclass classification, with levels and tables in accordance with ISO 12006-2 [21], which facilitates computer processing. Its list of entities contains buildings and civil infrastructures. It also contains a list of spaces and functional elements. Its main disadvantage is that the costs are organised into three different tables. Secondly, the levels established in the ICMS [34], which focus on the costs of the life cycle of any construction (building or infrastructure) are taken as a reference. It has a limitation in the division into categories of the life cycle however, which is not fully aligned with EN-15643 [10]. Finally, the ICMS classification is the closest to the objective proposed in this research. From the combination of the above, the levels are proposed in Table 3. The level dedicated to life cycle stages is aligned with EN-15643, another level is for the classification regarding building typologies as suggested by Uniclass [30] and the ICMS, and a functional group level enables cost elements to be organised, which is common to all reference classifications.

Table 3. Comparative structure of the reference and current proposed CICS. Levels of decomposition.

Uniclass Levels				
Table	Denomination	Level	Description	
Entities	Group Sub-group Section	N1 N2 N3	Grouping of buildings per use Sub-division of buildings per use Types of buildings	
Functional Spaces	Group Sub-group	N1 N2	Grouping of spaces or locations Spaces and locations	
Functional Elements	Group Sub-group	N1 N2	Grouping of Building Elements and Functions Elements and functions of the building	
ICMS Levels				
Main Levels		Level	Description	
Project		N1	Types of construction (building and civil)	
Cost Categories		N2	Division according to construction life cycle	
Cost Groups Cost sub-group		N3 N4	Construction Division Sub-division of Cost Groups	
New Proposal Levels				
Main Levels		Level	Secondary Levels	
Life cycle Categories		N1	n.1.1. n.1.2.	Categories Sub-categories
Functional Groups		N2	n.2.1. n.2.2.	Functional Groups Functional sub-groups
Type of building		N3	n.3.1. n.3.2. n.3.3.	Type of Family Type of Sub-family Type of Section

Level N1 divides the classification into categories within the stages of the building's life cycle. This level is divided into two sub-levels that are compatible with the levels represented in EN-15643 [10], which will also allow this classification to be used for environmental or social analysis. Level N2 enables the building to be divided into functional groups and sub-groups and relates them to each stage of the life cycle. Level 3, n3, comprises the building typologies, based on the classification of the Spanish Real Estate Cadastre [38]. Its sub-divisions of building typologies are hierarchical, from top to bottom, as follows: families, sub-families, and sections.

The coding of each element is formed by 10 digits (see Table 4). Numeric characters are used due to the universality of the code. The first two digits correspond to the life cycle categories. The next two digits are the functional groups. The third three-digit block identifies the construction type. And the last three digits establish the order of the functional elements belonging to the same level. Each primary or secondary level defined in the classification structure is assigned a numeric character (see Table 4).

Table 4. Numeric coding of the model. N represents a numeric character.

Level	Digits	Description			
N1	NN	Life Cycle			
N2	NN	Functional elements of the building			
N3	NNN	Type of building			
N4	NNN	Order Number			
		N1. NN.	N2. NN.	N3. NNN.	N4. NNN

3.1.1. Level 1—Life Cycle Categories

In Level 1, the CICS is structured according to the life cycle of the building, taking the EN-15643 standard as a reference. The first level, Categories, is made up of the following stages of the life cycle: pre-construction, construction, use, and end of life [10]. The following boundaries are established for each category:

- Pre-construction: costs from the completion of the preliminary studies, the acquisition of the land, and its transformation, until the moment at which the construction of the building begins. If the cycle begins with the acquisition of an existing building, only the work prior to its rehabilitation or transformation is included.
- Construction: all costs incurred from the beginning of the construction of the building until it is made available for use.
- Use: all costs dedicated to the use and maintenance of the building until the construction reaches its end of life.
- End of life: all costs necessary for the demolition or deconstruction of the building and the treatment of the waste generated.

The second sub-level is Sub-categories, which are those in the EN-15643 standard [10] with the addition of a further sub-category of fees and taxes, revenues, and other developer related overheads. These costs can be presented at any stage of the life cycle, as shown in Table 5. Another difference with respect to the standard is that the transport sub-categories (A2, C2) are not considered separately, but instead form part of each sub-category. This is due to the fact that, in Spanish traditional cost definitions, transport costs form part of each element of the building. The costs of basic elements always include their transport and unloading costs on site [35].

The boundaries of each sub-category of Level 1 are as follows:

- 01. Preliminary actions: The costs related to the purchase of the land where a new building is to be constructed or where an existing building is located. These costs also include all the necessary actions, fees, and management expenses of the developer before the start of the construction work.
- 09, 19, 29, and 39. Property developer’s income, taxation, professional fees, and other expenses: All professional fees, taxes, management expenses, and general expenses of the developer.
- 11. Building and outdoor spaces: All expenses related to the construction of the building related to the developer–construction contract.
- 21. Building use expenses: All contracted expenses and services not included in other sub-categories of building use (e.g., security, alarm, voice, and data installations).
- 22. Maintenance: All expenses for inspection, preventive and scheduled maintenance of the building so that it retains its characteristics of use (e.g., cleaning and painting).
- 23. Repair: Repair costs for unscheduled breakage or defects of building elements.
- 24. Replacement: The costs arising from the replacement of building elements that end their useful life before the end of the useful life of the building.

- 25. Refurbishment: Costs of major building modifications. These are only applicable in anticipation of legal or technological changes. In this research, transformations are not contemplated since they are considered to significantly alter the useful life of the building and to define a new life cycle of the building.
- 26. Operational energy use: Costs due to the building's energy consumption. Income from surplus energy production is considered in sub-category 29.
- 27. Operational water use: Costs for water consumption.
- 28. Occupant activities. Costs related to users or occupants of the building.
- 31. Demolition–deconstruction: Incorporates the costs of demolishing the building.
- 34. Waste management or landfill: Considers the costs of waste transport and management of any treatment, such as reuse, recycling, and landfill deposit. Income received from selling waste is considered a negative cost, as in ACCD [36].

Table 5. Level 1 categories and sub-categories. Life cycle. **NN**.NN. NNN. NNN, bolded the location of the code.

	Category		Sub-Category
0	Pre-construction	01	Preliminary work
		09	Income, taxation, professional fees, and other expenses of the developer
1	Construction	11	Building and outdoor spaces
		19	Income, taxation, professional fees, and other expenses of the developer
2	Use	21	Expenses of the building use
		22	Maintenance
		23	Repair
		24	Replacement
		25	Refurbishment
		26	Operational energy use
		27	Operational water use
		28	User activities
		29	Income, taxation, professional fees, and other expenses of the developer
3	End of Life	31	Demolition–deconstruction
		34	Waste management and/or landfill fees
		39	Income, taxation, professional fees, and other expenses of the developer

3.1.2. Level 2—Functional Groups

At Level 2, the sub-division of the buildings' functional groups is contemplated. A building can be defined as a "stable construction, made with resistant materials, to be inhabited or for other uses" [39], or by the following definitions provided by ASTM E631: "a shelter that comprises a partially or totally enclosed space, erected through a planned process of forming and combining materials" [40] and the ISO 6707-1:2020 definition of "a construction site whose main functions include housing its occupants or its contents; normally closed and designed to remain permanently fixed in place" [41]. Interpreting the above definitions and in order to establish the functions that the building must fulfil, it is understood that the building remains fixed in place and provides closed or partially closed spaces that enable them to be occupied.

Following the previous concepts, the organisation of functional groups is proposed in Table 6. For the configuration and use of this sub-level, the ICMS classification has been used as a reference. Specifically, it is proposed that the same classification of functional sub-group levels is repeated within each sub-category: construction, use, and end of life. Only the sub-categories referring to external costs of the building, such as land, and income, fees and taxes, professional fees and other expenses of the developer, will have a different structure. A sub-group is also included within each group that organises the functional areas.

Table 6. Building functional groups and sub-groups belonging to the life cycle sub-categories, 11, 21, 22, 23, 24, 26, 27, 28, 31, and 34. NN.**NN**. NNN.NNN, bolded the location of the code.

Functional Group N and Sub-Group NN		Boundaries
0	Pre-work and demolition	Activities prior to construction, replacement or repair work not related to building functions
00	Preliminary work and demolition	Functional areas of pre-work and demolition
01	Previous work	Preliminary work on the land or building not directly applicable to another functional element (e.g., prospecting).
02	Massive demolition	Massive demolition work of any existing functional element (no waste separation takes place during the demolition process)
03	Selective dismantling or demolition	Dismantling or selective demolition work (with separation of waste during the demolition process)
06	Waste management	Waste management during pre-work and demolition
07	Quality control	Quality control of previous work
08	Health and safety	Health and safety of previous work
09	Others	Other functional elements of pre-work and demolition
1	Sub-structures	Construction elements that transmit the building's loads to the ground, including earthworks and sanitary slabs and braced slabs
10	Sub-structures	Functional areas of sub-structures
11	Special	Special foundations, such as diaphragm walls
12	Surface	Foundation made by surface elements, such as footings or slabs, and the elements that support them directly (e.g., sanitary slabs and braced slabs)
13	Deep	Foundation made by deep elements, such as piles
16	Waste management	Foundation waste management
17	Quality control	Quality control of foundations
18	Health and safety	Health safety of foundations
19	Others	Other functional elements of foundations
2	Structures	Construction elements that transmit the loads of the use of the spaces to the foundations
20	Structure	Functional areas of structure
21	Porticoes	Structures made of porticoes and slabs
22	Space	Spatial structures
23	Vaulted	Spatial structures made by means of vaults
26	Waste management	Structure waste management
27	Quality Control	Structure quality control
28	Health and Safety	Structure health and safety
29	Others	Other functional elements of the structure
3	Installations	Construction elements that are responsible for facilitating use and maintaining comfort
30	Installations	Functional areas of installations
31	Affected	Elements from the external network to centralisation
32	Centralisation	Elements from connection to distribution
33	Distribution	Elements from centralisation to functional spaces
34	Production	Elements for the production of a supply
36	Waste management	Installation waste management
37	Quality Control	Installation quality control
38	Health and Safety	Installation Health and Safety
39	Others	Other functional elements of the installations

Table 6. *Cont.*

Functional Group N and Sub-Group NN		Boundaries
4	Envelope	Transitional construction elements between the exterior and interior spaces of the building
40	Envelope	Enclosure functional areas
41	Flat roofs	Upper building envelope with <5% inclination
42	Pitched roofs	Upper building envelope with high inclination >5%
43	Monolithic façades	Vertical building envelope in a single layer
44	Chambered or ventilated façades	Vertical envelope of several layers separated by air
45	Curtain walls	Vertical self-supporting enclosure, usually glazed
46	Waste management	Enclosure waste management
47	Quality Control	Enclosure quality control
48	Health and Safety	Enclosure health and safety
49	Others	Other functional elements of enclosures
5	Indoor Spaces	Construction elements that define the interior spaces of the building
50	Indoor spaces	Functional areas of indoor spaces
51	Specific	Use-specific functional spaces
52	Complementary	Functional spaces that complement specific spaces
53	Circulations	Transitional spaces that connect to interior spaces
56	Waste management	Indoor waste management
57	Quality control	Quality control of interior spaces
58	Health and safety	Health and safety of indoor spaces
59	Others	Other functional elements of interior spaces
6	Outdoor spaces	Construction elements outside the occupation of the building within the plot
60	Outdoor spaces	Functional areas of spaces outside the building within the plot
61	Plot enclosure	Transition element between the interior and exterior of the plot
62	Plot cover	Covered outdoor spaces
63	Open	Uncovered outdoor spaces
66	Waste management	Waste management of outdoor spaces
67	Quality control	Quality control of outdoor spaces
68	Health and safety	Health and safety of outdoor spaces
69	Others	Other functional elements of outdoor spaces

The inclusion of the groups that contain functional sub-groups related to waste management, quality control, and health and safety are of particular note. In addition to the costs directly associated with the buildings, it is necessary to consider the following other, indirectly related, costs in the sub-categories: preliminary actions, income, taxation, professional fees, and other expenses of the developer.

Table 7 shows the functional groups and sub-groups that form part of sub-category 01 of the life cycle, the preliminary work. These include the acquisition of land or existing buildings and related actions, such as the transformations carried out on the land before it became urban in relation exclusively to servicing the new building. In the case of an urban development that serves more than one building, it must be studied as an independent project by means of typology 9: Urbanisation (see Appendix A).

Table 8 describes the classification of sub-categories 09, 19, 29, and 39 for income, professional fees, and other expenses of the developer, including all expenses and income generated by the development activity, except costs due to land and building work and taxes. Income is generated by the use of the site or building, usually in the form of rent or assignments. Studies, projects, and construction management are the expenses for external professional services provided to the developer. Other expenses of the developer include those that can be imputed to the building and do not fit in other categories.

Table 7. Classification of functional elements of sub-category 01 of the life cycle: Preliminary actions of existing land or buildings (01.**NN**. NNN.NNN.), bolded the location of the code.

	Functional Group N and Sub-Group NN	Boundaries
1	Land preliminary work	
10	Land preliminary work	In functional areas, this is the preliminary land work referring to the land purchased
11	Rural land	Purchase of non-urban land
12	Management of urban transformations	Management, assignments, and agreements of urban transformations
13	Urban transformation work	Urban transformation work
14	Urban land	Acquisition of land that does not require urban transformations
19	Others	Other functional land-related functional areas
2	Preliminary building actions	
20	Preliminary actions in building	In functional areas, these are preliminary actions related to the building purchased to transform
21	Building	Acquisition of an existing building to be rehabilitated or conserved
22	Pre-rehabilitation work	Urgent consolidation and stabilisation work not related to the main work
29	Others	Other functional cells related to building

Table 8. Classification of functional elements for life cycle sub-categories 09, 19, 29, and 39 for revenue, taxation, professional fees, and other developer expenses. NN.**NN**. NNN. NNN, bolded the location of the code.

	Functional Group/Sub-Group	Boundaries
1	Income	
10	Income	Functional areas of the revenue generated by the site or building
11	Exploitation of assets	Income received from the operation of the building or land
12	Sale of goods	Partial sale of buildings or land that do not form part of the post-construction building
13	Other royalties or property rights	These include advertising revenue, rights to use the land, and easements at any stage of the life cycle
14	Grants	Grant income
19	Others	Income not covered above
2	Studies, projects, and directions	
20	Studies, projects, and directions	Functional areas of expenditure for study, projects, and management services
21	Feasibility studies	These include any previous studies (economic, environmental, or technical)
22	Urban or environmental studies and projects	These include any study and project (technical or environmental) linked to the urban transformation of the land related to the building
23	Blueprints	Preliminary studies of the design of the building
24	Building projects	Basic and execution project of the building
25	Site management	This includes professional services, such as construction management, health and safety coordination, quality control, and technical advice on the construction site
26	Comprehensive project management	Includes professional services for comprehensive project management
29	Others	Any expense not contemplated in previous sections of professional services
3	Developer's other expenses	
30	Developer's other expenses	Functional area of the developer's other expenses
31	Assessment	Expenses for the appraisal of the building during the life cycle
32	Marketing	Expenses related to the marketing of the building
33	Notary, registries, and cadastre	Expenses related to legal operations of transmissions and registry of the building
34	Insurance	Property insurance expenses and their transformations
35	Financial expenses	Fees and interest expenses related to financial transactions
38	Developer overhead	The developer's own expenses not related to a specific building
39	Others	Any expense not contemplated in previous sections of the property developer
4	Taxation	
40	Fees and taxes	Functional areas of the fees and taxes supported by the construction of a building
41	City fees and taxes	Municipal fees and taxes
42	Regional fees and taxes	Regional fees and taxes
43	State fees and taxes	State Fees and taxes
49	Others	Other functional cell fees and taxes

3.1.3. Level 3—Building Typologies

The third and final level refers to the definition of the building typologies classification based on the Spanish Real Estate Cadastre [38]. Each element of the typology classification is defined in Appendix A. The classification of construction typologies is organised in three levels. First, the general building uses are grouped into the following nine main categories: 1. Commercial, 2. Sport, 3. Hospitality, 4. Warehouses, 5. Leisure, 6. Teaching, 7. Residential, 8. Healthcare, and 9. Urbanisation. The last category, although it is not directly related to buildings, is included as an exception since it is considered necessary when the development costs are not due to a single building. In sub-levels, the typologies are grouped according to the building's specific uses. For example, within the hospitality classification, there are the sub-families of lodging and catering. In its sub-level 3.2, within the catering sub-family, would be the bar, cafe, and restaurant sections.

3.2. Costs of Functional Spaces

In Appendices A–E, examples are given of the methodology applied to the creation of functional costs of construction, maintenance, repair, and replacement. The functional cell space corresponds to the corridor of a secondary school building in Andalusia. The corridor's functional cell cost, which is measured per usable area, is described in Appendix B. This consists of the ceiling, floor, lighting, electrical installation, fire protection system, and speakers. The walls of the corridor are included in other cells, such as interior partitions and façades. The cost calculation is performed by aggregating the work unit costs that are presented in the functional cell. The quantities of each unit cost depend on the proportion that corresponds to that area.

The corridor's functional cell has the coding 1153613001, which corresponds to category 1 construction, sub-category 1: building and exterior spaces, 5 for indoor functional spaces, 3 for circulations, 6 for teaching building, 13 for secondary school, and 001 is the cost order number. The unitary costs that form the functional cell are obtained from the regional construction cost database ACCD. In order to establish the quantities of each unitary cost, such as the corridor surface, in the project this is 263.89 m^2 and has three loudspeakers. The quantity to be considered in the cell is six units/263.89 m^2 = 0.02272 u/m^2. The functional cell is formed by unit costs at the base of the cost pyramid, Figure 4.

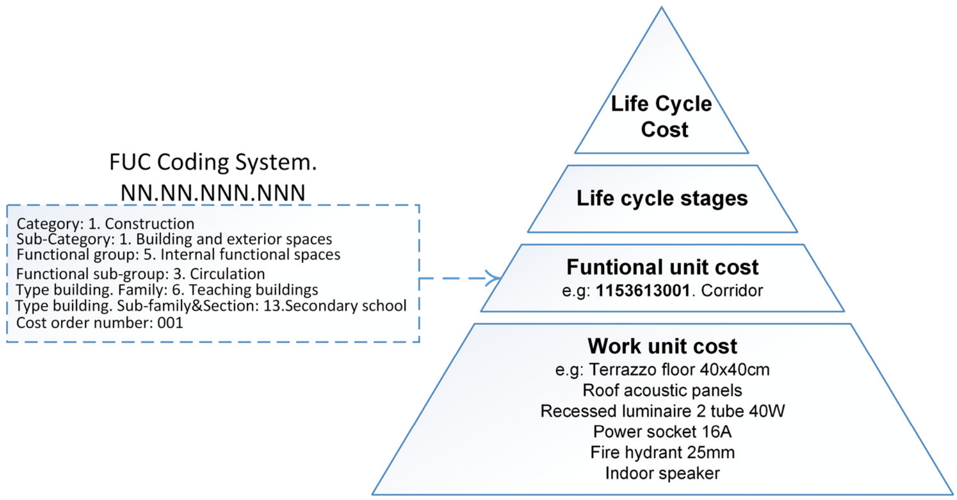

Figure 4. Cost structure, the work unit cost is obtained from the ACCD which is part of the functional cost.

The maintenance costs of the functional cell refer to the preventative tasks that must be carried out in order to maintain it in good condition (see Appendix C). The cost of repairs is an annual proportion of each element and is calculated as a percentage of each construction cost that makes up the functional cell (see Appendix D). The percentages are based on "The

Whitestone Installation Maintenance and Repair Cost Reference" [42] or on the EN-15459-1 standard [43].

Replacement costs correspond to the substitution of elements that form part of the functional cell, since their useful life ends before that of the building. They include the costs of the small demolitions required to carry out the replacement. An example is given in Appendix E.

The costs of functional cells are combined into a functional area. In Appendix F, there is an example of the area "circulation zone in a secondary school". The functional area is the result of adding functional cells and their corresponding quantities.

Finally, the functional costs form an LCC database of construction maintenance, repair, and replacement costs. For the calculation of the LCC it is necessary to define the building's general characteristics or design parameters that describe the geometrical aspects of the functional spaces. Other aspects needed are the economic parameters; in this case, the discount rate to be applied to the cost estimation. This calculation is performed per stage of the life cycle (see Figure 5).

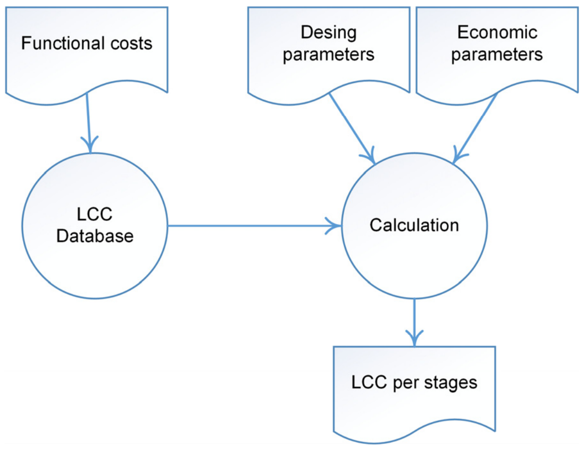

Figure 5. Steps for the calculation of the life cycle cost (LCC) of the project per stage.

3.3. Case Study

A public school building built by the regional government is studied, whose standardization and representativeness of secondary schools in Andalusia, Spain allows the application and validation of the model. The D3 typology of the regional government has been chosen [44]. It is a fourth-year teaching building, divided in three classrooms per year, with a capacity of 30 students each. Three projects studied are built in the municipalities of Palomares, Almensilla, and Marbella. From those, a generic secondary school is defined. In Figure 6, a representative floor is shown, and in Table 9, the space distribution per square metre.

The duration of the pre-construction, construction, and end-of-life stages is 1 year each. The use stage lasts 100 years in order to meet Spanish requirements for concrete structures [45]. Maintenance tasks take place annually except for painting which occurs every five years. Repairs are annual and the following substitutions are at 20 years: HVAC, electronics, bathrooms and kitchens; the following at 40 years: HVAC, electronics, other installations, bathrooms and kitchens, elevators, envelope repair, ceilings; and the following at 70 years: the same activities as at 40 years but, additionally, the floor is replaced.

The following four hundred and sixty functional costs were defined: five for the pre-construction stage, 108 for the construction, 338 for the use stage and nine for the end-of-life stage. The utilities consumption was obtained from the public school system's actual data. The water consumption is 640 m^3/year, the power consumption is 40,000 kWh/year, gas consumption is 20,000 kWh/year, and data and telephonic communications are EUR 790/year. The cost of urban land in the province of Seville was obtained from official statistics (EUR 154.20/m^2) [46]. The taxes were taken from local (Seville), regional (Andalusia), and national (Spain) regulations [47].

Table 9. Description of the project floor area.

Project General Characteristic	**Floor Area (m^2)**
Lot size	6.000
Gross external/usable area coefficient	1.15
Total gross external area of buildings	3.450
Total surface area occupied by outdoor spaces	3.942
Total building floor area	2.058
Breakdown indoor spaces (usable area)	
Specific functional spaces	1510
Multipurpose classrooms	720
Music Lessons classrooms	60
Special education classrooms	50
Plastic art classrooms	60
Workshop classrooms	100
Laboratory rooms	60
Integration support rooms	60
Sport rooms	400
Complementary spaces	750
Circulations spaces	740
Total indoor spaces	3000

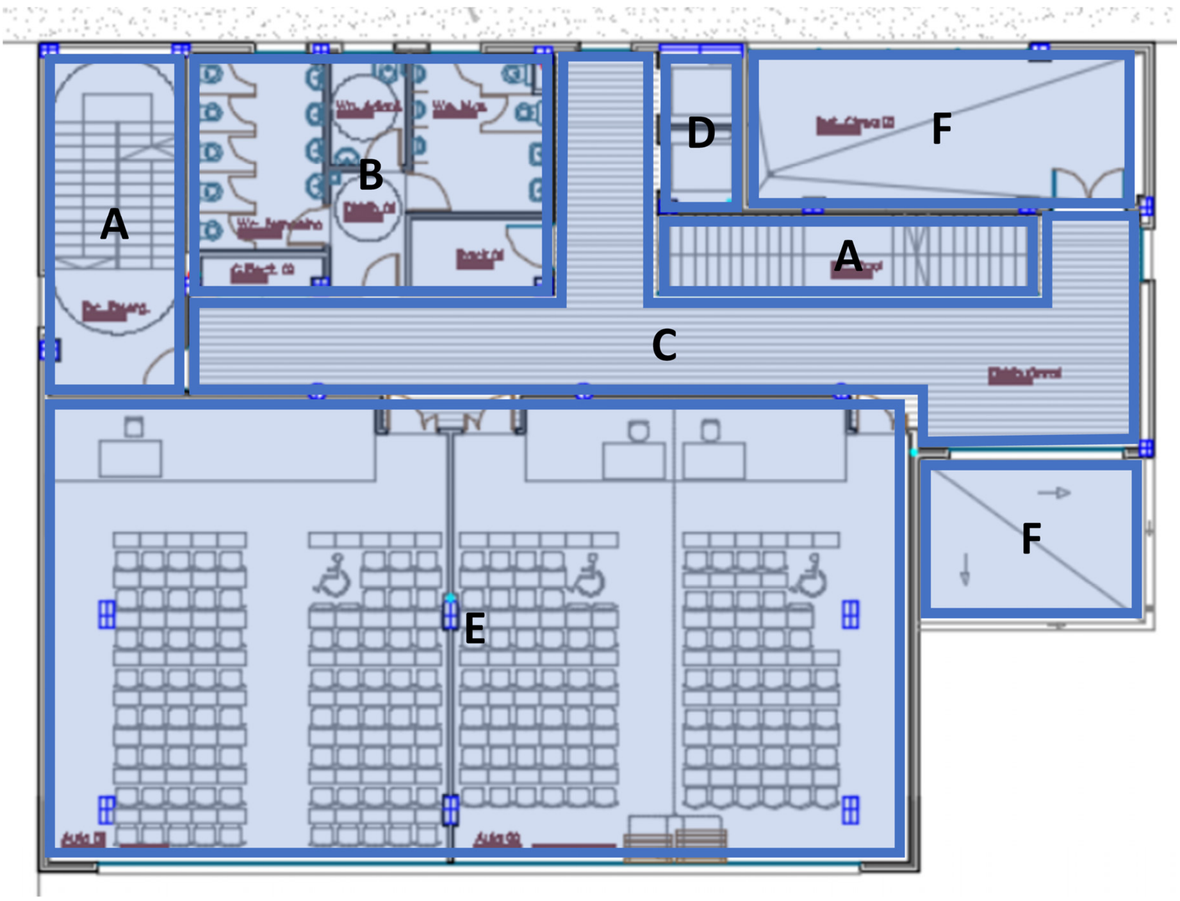

Figure 6. Example functional spaces ((**A**). Staircase, (**B**). Lavatory, (**C**). Corridor, (**D**). Lift, (**E**). Classroom, (**F**). Terrace).

4. Results

The results are obtained by stages of the life cycle, analogous to environmental product declarations, and by functional spaces, allowing for the identification of the most expensive elements. Finally, future investment costs in the life of the building can be determined from the early design stages. The results have been obtained for a discount rate of 0% and 3%, in the calculation of the 100-year LCC (Figure 7).

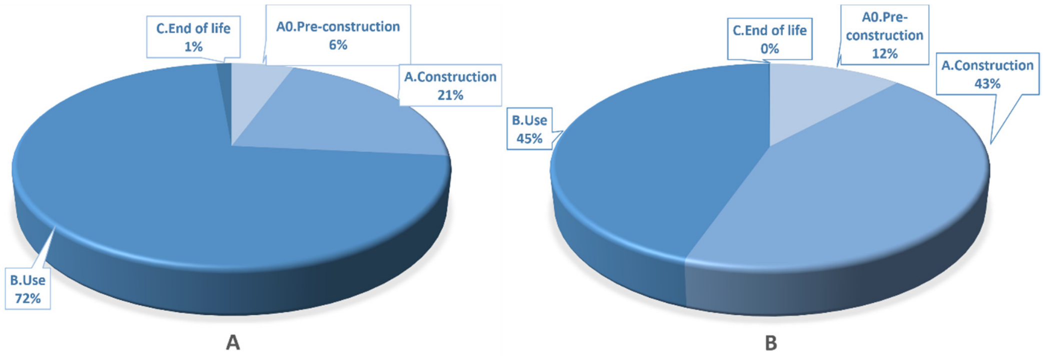

Figure 7. Comparison of LCC category percentages with different discount rates of 0% (**A**) and 3% (**B**).

The most expensive stage is B. Use, followed by A. Construction. The effect of the discount rate in the calculations appreciates, since it clearly reduces the influence of the use stage when the 3% discount is applied. The A0. Pre-construction costs are also significant, but not included in other studies [23].

Analysing the decomposition of data from the different stages, see Figure 8, the most impacting stage of the building life cycle is B2. Maintenance, followed by B4. Substitutions, both with economic impact higher than stages A1–A4 Construction. B3. Repairments is the fourth must impacting stage. The utilities consumption rates are not very significant and are similar to those of developer expenses and taxation. It can be seen that the discount rate reduces the importance of subcategories B2 and B4 in the 3% discount rate.

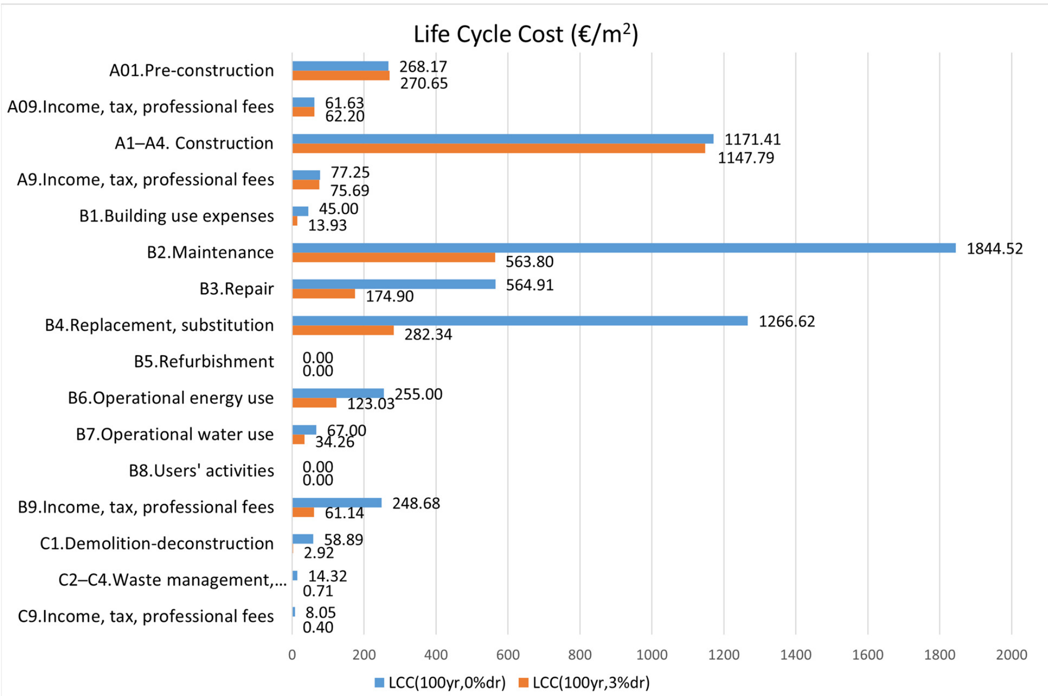

Figure 8. The costs per life cycle subcategories with 0% (blue) and 3% (orange) discount rates.

The results can be compared to C. Rivero-Camacho et al. [3]. They studied social housing in the same region and employed the ACCD for the unit cost data. Their discount rate was 0%. In Table 10 their results are compared to the present work. Although the buildings have different purposes, residential vs. secondary school, the results are similar in terms of percentage. It should only be noted that the B stage or use in the school building is more influential than in the case of the residential building. Even though Rivero-Camacho et al. employed the actual project data and in the present work a simplification functional costs were applied (those being feed by unit costs of the same data base). The results show that the functional costs can be a good approximation to the project's LCC.

Table 10. Comparative results between the secondary school and a social housing project. The percentage of each stage and in parenthesis the cost per square metre.

Stage	Secondary School % (€/m^2)	Four Stories Residential % (€/m^2)
A0. Pre-construction	5.5 (329.81)	11.3 (329.81 *)
A. Construction	21.0 (1248.66)	21.9 (635.29)
B. Use	72.1 (4291.73)	65.5 (1904.80)
C. End of life	1.4 (81.26)	1.3 (37.36)
LCC	100 (5951.45)	100 (2907.26)

* The value of the land has been estimated using the same source as in the case study in order to facilitate the percentage comparison.

5. Discussion

The new classification considers the ISO 12006-2 normative framework [21], the EN-15643 standard [10], since it is a life-cycle structure, and the ISO classification [9]. But the separation of the LCC and CGCV concepts in the ISO standard is shown to be unnecessary because pre-construction externalities, revenues, and costs can all be included as sub-categories within each stage of the life cycle. ISO 12006-2's main disadvantage is that the costs are organised into three different tables. For this, ICMS is taken as a reference because it is the closest to the objective proposed in the present research, which focuses on the costs of the life cycle, even though it is not fully aligned with EN-15643.

The sub-categories proposed are those in the EN-15643 standard [10], with the addition of a further sub-category of fees and taxes, revenues, and other developer related overheads. These costs can be presented at any stage of the life cycle. Another difference with respect to the standard is that the transport sub-categories (A2, C2) are not considered separately, but instead form part of each sub-category. This is due to the fact that in traditional Spanish cost definitions the costs of basic elements always include their transport and unloading costs on site [35].

From the combination of the above, the levels are (1) life cycle categories, (2) functional groups and (3) building typologies. The level dedicated to life cycle stages is aligned with EN-15643 [10], another level is for the classification regarding building typologies as suggested by Uniclass [30] and the ICMS [34], and a functional group level enables cost elements to be organised; this is common to all reference classifications.

The results show that this new CICS allows the generation of a robust structure that first contains the different stages of the life cycle of the functional element under analysis. Second, it analyses the functional element and establishes clear boundaries, and, lastly, it specifies this element in the building typology, which in this case is a teaching centre. The aggregation of the costs of elements and functional areas generates the structure of the estimate that in turn leads to the determination of the LCC of the building to be analysed. All this suggests that the definition of the functional costs needs to be performed by experts with knowledge of construction and previous experience of the building typology.

In summary, in a novel way, the proposed systematic classification covers the entire life cycle, being aligned with the standards for environmental sustainability assessment EN-15643 [10]. It enables early estimates of life cycle cost, using functional costs in a novel way to estimate construction and maintenance costs. The classification also clearly includes taxes, fees, and financial expenses at different stages of the life cycle. It is the first Spanish work breakdown system that includes all these aspects.

6. Conclusions

In order to understand how a CICS is developed, the main international and regional CICSs have been analysed. Their comparison has been carried out using eight criteria: purpose and properties, framework, the principles of grouping, the organisation of the classification models, scope of use, coding, life cycle, and scope boundaries. The comparison reveals a fairly complete picture of the organisation and classification.

A new classification is proposed with the following three levels: life cycle categories, functional groups, and building types. The level dedicated to life cycle stages is aligned with EN-15643. The functional group level enables cost elements to be organised, and the third level is for the classification of building typologies as suggested by Uniclass and the ICMS.

A cost structure has been possible that defines and meets the objectives for environmental sustainability assessment. The new classification employs the stages of the life cycle of the EN-15643, A0-pre-construction, A-construction, B-Use and C-end-of-life in a way equivalent to that which appears in the environmental product declarations, but at the building level. New sub-categories are included, such as income, professional fees, other expenses of the property developer, and tax costs. This makes it possible to attribute them individually to each stage of the building's life and to study them in detail.

For the evaluation of costs during the early stages of the design, these are defined as functional costs. For their definition, it is necessary to gather information from similar previously tendered projects, from the design regulations, and from the actual costs of supplies from construction cost databases.

The case study of a secondary school project in Andalusia shows that the use stage is important as compared to other costs. This makes crucial the correct definition of all future repair work and maintenance tasks, as well as the utility consumption of the building. The new CICS can be aligned with the sustainability assessment stages.

In future work, the methodology will be applied to entire building projects, and will define their cells and functional spaces in order to carry out the complete life cycle cost assessment procedure. This can be performed for a variety of building typologies, such as residential buildings, offices, and educational centres, in order to determine whether this classification effectively covers the LCC in the early stages of design. Furthermore, the influences of inflation, discount rates, and life cycle duration could also be taken into consideration.

The integration of this classification system into the determination of the LCC indicator is also proposed in evaluation tools such as Level(s) and BREEAM, as is its integration into BIM environments regarding the functional costs created. Likewise, future research is proposed regarding the in-depth determination of LCC in terms of the new CICS.

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Appendix A

Table A1. Sections of the division of building typologies (NN.NN.**NNN**. NNN), bolded the location of the code.

	Classification	Boundaries
1	Commercial, offices, and parking	Buildings intended for commercial use, offices, and parking
11	Bureaux	Buildings with the purpose of providing professional, management or administrative services
111	Bank	Buildings for the purpose of providing banking services
112	Administrative	Buildings for the purpose of providing professional or administrative services
113	Institutional	Institution Management Building
119	Others	Office buildings not previously contemplated
12	Commercial	Buildings intended for the sale of products or services
121	Commercial premises	Buildings intended for the sale of products or services located on the ground floor
122	Shopping centre	Buildings intended for a group of shops or that are a single shop on several floors
129	Others	Commercial buildings not previously contemplated
13	Parking	Buildings or spaces intended for vehicle parking
131	Underground parking	Below-ground parking building
132	High-rise parking	Building for parking above ground
139	Others	Other types of parking buildings
19	Others	Commercial buildings or offices not included above
199	Others	Other buildings
2	Sports facilities	Buildings intended for sport activities
21	Golf courses	Ground area and buildings intended for golf
211	Golf course	Ground used for golf
219	Others	Others
22	Tracks	Ground area and buildings intended for outdoor sports on tracks
221	Arid	Tracks of arid material
222	Lawn	Natural grass courts
223	Monolayer	Single-layer rigid tracks
224	Multilayer	Multi-layered tracks
225	Special	Natural grass courts
229	Others	Other Clues
23	Stadiums and grandstands	Buildings intended to house the public for sporting events
231	Stadiums	Large enclosure with grandstands for sports activities
232	Covered grandstands	Covered area to accommodate the public
233	Outdoor grandstands	Uncovered enclosure to accommodate the public
239	Others	Others

Table A1. *Cont.*

	Classification	Boundaries
24	Pools	Buildings intended for water sports developed in swimming pools
241	Indoors	Indoor swimming pool area
242	Outdoors	Outdoor swimming pool enclosure
249	Others	Others
25	Sports hall	Buildings intended for the exercise of various indoor sports
251	Sports hall	Buildings intended for the exercise of various indoor sports
259	Others	Others
26	Gymnasium	Buildings where gymnastics is practiced
261	Gymnasium	Buildings where gymnastics is practiced
269	Others	Others
29	Others	Sports buildings not described above
299	Others	Others
3	Hospitality industry	Buildings intended for hotel and restaurant use
31	Lodging	Buildings intended for the accommodation of people
311	Tourist apartments	Residential space or building dedicated to hospitality in an urban environment
312	Bed and Breakfasts	Residential space or building dedicated to hospitality in a rural environment
313	5-star hotels	5-star hotel category
314	4-star hotels	4-star hotel category
315	Other hotels, and hostels	Other categories of hotels or hostels
319	Others	Others
32	Catering	Spaces or buildings intended for the consumption of beverages and food
321	Bars	Drinks service taken while standing
322	Cafes	Food and beverage service without kitchen
323	Restaurants	Meal service with tables and kitchen
329	Others	Others
39	Others	Hospitality spaces or buildings not mentioned above
399	Others	Others
4	Warehouses	Large-capacity buildings intended for manufacturing, storage, agricultural production, or commerce
41	Open	Warehouse with an open façade
411	Agricultural	Warehouse for agricultural use
419	Others	Warehouse not previously described
42	Closed	Warehouse with all façades closed
421	Agricultural	Warehouse for agricultural use
422	Industrial	Warehouse for industrial use
423	Commercial	Warehouse for commercial use
424	Warehouse	Warehouse for storage
425	Logistics	Warehouse for logistics storage
429	Others	Others
49	Others	Warehouse not previously described
499	Others	Others

Table A1. *Cont.*

	Classification	Boundaries
5	Leisure	Buildings intended for both indoor and outdoor leisure
51	Covered	Buildings intended for indoor leisure
511	Social club	Meeting Spaces
512	Discotheques	Rooms dedicated to nightlife
513	Gaming floors and casinos	Spaces intended for gambling
514	Theatres and cinemas	Exhibition space for theatrical or cinematographic works
515	Palais des Congrès	Building for holding congresses and exhibitions
519	Others	Other leisure spaces not identified above
52	Open air	Outdoor spaces or buildings
521	Auditorium	A space dedicated to the gathering and representation of artistic works in the open air
522	Bullring	Space dedicated to the practice of bullfighting
529	Others	Others
59	Others	Other typologies not described above
599	Others	Others
6	Teaching and cultural	Buildings designed to house educational and cultural spaces
61	Teaching buildings	Building intended for pre-university teaching activity
611	Nursery schools	Space dedicated to teaching between 0- and 2-year-olds
612	Infants and primary	Building dedicated to teaching between 3- and 12-year-olds
613	Secondary school	Building dedicated to teaching between 13- and 17-year-olds
614	Vocational training cycles	Building dedicated to professional education
619	Others	Others
62	University	Building intended for university teaching activity
621	Lecture Hall	Building intended for university face-to-face teaching
622	Faculty or School	A building intended for the university teaching of certain subjects
623	Research Centre	Building for research in the university environment
629	Others	Others
63	Cultural	Building for cultural activities not idle
631	Libraries	Building for archiving, classifying, and consulting bibliographic material
632	Municipal art centres	Building intended for cultural uses
633	Museums	Exhibition space for artistic objects
639	Others	Various cultural buildings
64	Religious	Building or space intended for religious worship
641	Religious	Building for worship and religious gatherings
649	Others	Others religious buildings
69	Others	Educational, cultural, and institutional buildings not included above
699	Others	Others

Table A1. *Cont.*

	Classification	Boundaries
7	Residential	Buildings intended for residential use
71	Residential block	High-rise multi-family residential buildings
711	Isolated	High-rise dwellings without party walls in common with another building
712	Attached	High-rise dwellings with party walls in common with another building
719	Others	Others
72	Single-Family homes	Single-family residential buildings
721	Isolated	Single-family homes without party walls in common with another building
722	Attached	Single-family homes with party walls in common with another building
729	Others	Others
79	Others	Other type of residential building
799	Others	Others
8	Health and welfare	Buildings intended for health or welfare use
81	Clinic and health centres	Buildings or spaces dedicated to primary care or family medicine
811	Consulting room	Spaces for consultations and patient care
812	Health Centre	Building for outpatient consultations and treatment
819	Others	Miscellaneous primary care
82	Hospitals	Building for the diagnosis, treatment, and accommodation of patients
821	Hospitals	Building for the diagnosis, treatment, and accommodation of patients
829	Others	Others
83	Health clinics	Establishment dedicated to the diagnosis and treatment of diseases
831	Physiotherapy	Establishment dedicated to the treatment of trauma or injury
832	Dentistry	Establishment dedicated to dental treatment
833	Ophthalmology	Establishment dedicated to eye treatment
834	Radiology	Diagnostic facility using radiology
839	Others	Others
84	Geriatrics	Building intended for geriatric accommodation
841	Day care centres	Geriatric day-stay building
842	Geriatric residence	Geriatric housing building
849	Others	Others
85	Funeral	Building intended for the burial or treatment of corpses
851	Funeral homes	Building intended for the treatment of corpses prior to burial
852	Cemetery	Space for the burial of corpses
859	Others	Others
86	Prison	Construction of a prison for offenders
861	Prison	Construction of a prison for offenders
862	Juvenile offenders centre	Construction of detention centre for juvenile offenders
869	Others	Others

Table A1. *Cont.*

	Classification	Boundaries
87	Veterinarian	Space for the treatment of animals
871 879	Veterinarian Others	Space for the treatment of animals Others
89	Others	Other healthcare spaces not included above
899	Others	Other healthcare spaces not included above
9	Urbanisation	Land preparation for building plots (only actions that cannot be assigned to a single building)
91	Terrain	Preparation of rural land for its transition to urban
911 919	Terrain Others	Develop a plot of land Others
99	Others	Others
999	Others	Others

Appendix B

Table A2. Example of construction cost of functional cell.

1153613001	**m^2**	***Corridor***			
Corridor of a secondary school, including cladding (except partitions with uses) and installations from distribution. Measured in terms of usable area.					
Code	**Unit**	**Concept**	**Quantity**	**Cost (€)**	**Amount (€)**
10STS90010	m^2	*Terrazzo floor with small grain 40* cm × *40* cm	1.00000	21.28	21.28
10SER00001	m^2	*Stainless steel skirting board 2* mm *and 7* cm	1.00000	11.64	11.64
09TSS00010	m^2	*Insulation of rigid polyester plank floors Extended 20* mm	1.00000	6.74	6.74
10TWW90013	m^2	*Roof acoustic panels, removable and concealed truss*	0.53776	62.81	33.78
10TWW00011	m^2	*Continuous ceiling with laminated plasterboard*	0.46224	20.15	9.31
09TTT00100	m^2	*Insulated felt roofs with fibreglass, 20* mm	1.00000	15.94	15.94
13EAA00001	m^2	*Smooth acrylic elastomer paint*	0.46224	3.67	1.70
08ETT00003	unit	*16 A recessed power socket with 2.5* mm^2	0.03789	37.06	1.40
08PIS00031	unit	*Emergency lighting and signal equipment, 160 lumens*	0.04547	72.68	3.30
08WII00135	unit	*Recessed luminaire 2 tubes 40* W. *30* mm × *30* mm	0.09095	125.28	11.39
08PID00101	unit	*Push button for manual surface alarm triggering*	0.01137	22.07	0.25
08PIE90023	unit	*Mobile fire extinguisher, ABC powder, 6* kg	0.03032	28.74	0.87
08PID90200	unit	*Indoor buzzer*	0.01137	21.89	0.25
08PIS90107	unit	*Label 297* mm × *210* mm	0.06442	10.74	0.69
08PIE90013	unit	*Fire hydrant 25* mm *diameter and cabinet*	0.01137	501.84	5.71
08DA00201	unit	*Indoor speaker*	0.02274	120.29	2.74
				Total	**126.99**

Appendix C

Table A3. Example of the cost of maintaining functional space.

2353613001	**m^2**	***Annual Corridor Maintenance***			
Annual maintenance of corridors including the revision and maintenance of fire extinguishers and BIEs. Measured in terms of usable ground area					
Code	**Unit**	**Concept**	**Quantity**	**Cost**	**Amount**
20IPC00001	unit	*Revision and maintenance of manual fire extinguisher up to 6* kg	0.03032	3.79	0.11
20IPC00005	unit	*Overhaul and maintenance of equipped fire hydrants*	0.01137	7.57	0.09
				Total	**0.20**

Appendix D

Table A4. Example costs of functional space repairs.

2353613001	**m^2**	***Corridor repairs annually***				
Annual repairs in the corridor of a secondary school including cladding (except divisions with uses) and installations from distribution. Measured in terms of usable ground area of the functional space						
Code	**Unit**	**Concept**	**% Rep.**	**Quantity**	**Cost**	**Amount**
10STS90010	m^2	*Terrazzo floor with small grain 40* cm × *40* cm	0.13	0.00130	21.28	0.03
10SER00001	m^2	*Stainless steel skirting board 2* mm *and 7* cm	0.13	0.00130	11.64	0.02
09TSS00010	m^2	*Insulation of floor with rigid polyester plank, 20* mm *thick*	0.13	0.00130	6.74	0.01
10TWW90013	m^2	*Roof acoustic panels, removable and concealed truss*	0.08	0.00043	62.81	0.03
10TWW00011	unit	*Continuous ceiling with laminated plasterboard*	0.08	0.00037	20.15	0.01
09TTT00100	unit	*Roof Insulation with fibreglass felt, 20* mm *thick*	0.08	0.00080	15.94	0.01
13EAA00001	unit	*Smooth acrylic elastomer paint*	0.08	0.00037	3.67	0.00
08ETT00003	unit	*16 A recessed power socket with 2.5* mm^2	1.00	0.00038	37.06	0.01
08PIS00031	unit	*Emergency lighting and signal equipment, 160 lumens*	1.50	0.00068	72.68	0.05
08WII00135	unit	*Recessed luminaire 2 tubes 40* W, *30* mm × *30* mm	1.50	0.00136	125.28	0.17
08PID00101	unit	*Push button for manual surface alarm triggering*	1.00	0.00011	22.07	0.00
08PIE90023	unit	*Mobile fire extinguisher, ABC powder, 6* kg	8.30	0.00252	28.74	0.07
08PID90200	unit	*Indoor buzzer*	1.00	0.00011	21.89	0.00
08PIS90107	unit	*Label 297* mm × *210* mm	2.00	0.00129	10.74	0.01
08PIE90013	unit	*Fire hydrant 25* mm *diameter and cabinet*	2.00	0.00023	501.84	0.12
08DA00201	unit	*Indoor speaker*	2.00	0.00045	120.29	0.05
					Total	**0.59**

Appendix E

Table A5. Example of costs of replacements in functional space.

2353613071	**m^2**	***Replacements year 70. Corridors***			
Year 70 replacements in corridors of construction elements including floors, ceilings and installations including demolition, excluding floor insulation and painting (maintenance). Measured in terms of usable ground area of the functional space					
Code	**Unit**	**Concept**	**Quantity**	**Cost**	**Amount**
10STS90010	m^2	*Terrazzo floor with small grain 40* cm × *40* cm	1.00000	21.28	21.28

Table A5. *Cont.*

2353613071	**m^2**	***Replacements year 70. Corridors***			
Year 70 replacements in corridors of construction elements including floors, ceilings and installations including demolition, excluding floor insulation and painting (maintenance). Measured in terms of usable ground area of the functional space					
Code	**Unit**	**Concept**	**Quantity**	**Cost**	**Amount**
10SER00001	m^2	*Stainless steel skirting board 2* mm *and 7* cm	1.00000	11.64	11.64
10TWW90013	m^2	*Roof acoustic panels, removable and concealed truss*	0.53776	62.81	33.78
10TWW00011	m^2	*Continuous ceiling with laminated plasterboard*	0.46224	20.15	9.31
09TTT00100	m^2	*Roof Insulation with fibreglass felt, 20* mm *thick*	1.00000	15.94	15.94
13EAA00001	m^2	*Smooth acrylic elastomer paint*	0.46224	3.67	1.70
08ETT00003	unit	*16 A recessed power outlet with 2.5* mm^2	0.03789	37.06	1.40
08PIS00031	unit	*Emergency lighting and signal equipment, 160 lumens*	0.04547	72.68	3.30
08WII00135	unit	*Recessed luminaire 2 tubes 40* W*, 30* mm × *30* mm	0.09095	125.28	11.39
08PID00101	unit	*Push button for manual surface alarm triggering*	0.01137	22.07	0.25
08PIE90023	unit	*Mobile fire extinguisher, ABC powder, 6* kg	0.03032	28.74	0.87
08PID90200	unit	*Indoor buzzer*	0.01137	21.89	0.25
08PIS90107	unit	*Label 297* mm × *210* mm	0.06442	10.74	0.69
08PIE90013	unit	*Fire hydrant 25* mm *diameter and cabinet*	0.01137	501.84	5.71
08KIA00201	unit	*Indoor speaker*	0.02274	120.29	2.74
01RST90002	unit	*Selective demolition with mechanical means of terrazzo flooring and skirting boards*	1.00000	5.86	5.86
01RTE90100	unit	*Selective demolition of continuous plasterboard ceiling*	1.00000	3.40	3.40
01IEW90055	unit	*Massive manual demolition of electrical installation in functional space < 100* m^2	1.00000	0.57	0.57
				Total	**130.08**

Appendix F

Table A6. Example of costs of construction in functional area space.

1150613001	**m^2**	***Functional area of circulations in a secondary school***			
Understanding the spaces of corridors and stairs of communication between floors of the building. Measured in terms of usable ground area of the functional space					
Code	**Unit**	**Concept**	**Quantity**	**Cost**	**Amount**
1153613001	m^2	*Corridor*	0.76351	166.23	126.92
1153613002	m^2	*Staircase starting section with storage*	0.10135	465.04	47.13
1153613003	m^2	*Staircase on the middle floor*	0.03378	450.31	15.21
1153613004	m^2	*Landing space stairway*	0.10135	224.00	22.70
				Total	**211.96**

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