Performing a Life Cycle Costs Founding Model: Design and Analyses

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Abstract

Life cycle costing is currently present in a significant number of international and european normative documents – related to the management of physical assets – as a supporting tool to decision making. The universal concern to promote the application of this methodology emphasizes its relevance to get the best management outcomes in the Arquiteture, Engeneering and Construction industry. Nevertheless, the theoretical potenciality of this methodology needs practical results. Therefore, in this document a founding cost model is being developed according to the requirements of the European standards EN 15643-4 and EN 16627, concerning assessment of the economic performance of buildings. The case study intends to analyse the feasibility of the refered standards through the built model.

1. Introduction

The process of identifying and documenting all the costs involved over the life of an asset is known as Life-Cycle Costing (LCC). The future costs should be considered along with the inicial capital if the best outcome is to be achieved (ANAO; 2001). Owners, users and managers need to make decisions on the acquisition and ongoing use of many different assets and the LCC is a support tool to making decisions, reflecting the real impact of an investment.

The LCC concept arised at 1950 in the military industry and then began to appear in construction industry. This term was developed in different studies and discussed on several publications, reaching a final definition in 2008 by the scientific community. The LCC concept was published in the international standard ISO 15686-5, where it is defined as *the cost of an asset or its parts throughout its life cycle, while fulfilling the performance requirements* (ISO 55000; 2014). This standard also stated that a methodology for systematic economic evaluation of life-cycle costs over a period of analysis, as defined in the agreed scope, should be done. LCC supports decision making, allowing the visibility of the total costs of the assets and enhancing the choice of the best solution (Assis, Julião; 2009).

Another important concept to the LCC matter is the asset management (AM). People have been managing assets for thousands of years, but the real concept appeared only in 2004 with PAS 55 specification. This document was the basis to develop the recent family of standards ISO 55000 (2014), where asset management is defined as the coordinated activity of an organization to realize value from assets (something that has potential or actual value to an organization) and that value is accomplished by balancing costs, risks, opportunities and performance benefits, at different timescales. The correct AM will combine the technical decisions with the management decisions, show the global costs clearly, set realistic budgets and justify investments (Assis, Julião; 2009).

LCC has been a matter of study and development by different recognized standards bodies, such as the International Organization for Standardization (ISO) and the European Committee for Standardisation (Comité Européen de Normalisation, CEN), which highlight the relevance of this tool.

2. Legal and Regulatory Framework

There are several standards that accentuate the importance of LCC to the better management of the Arquiteture, Engineering and Construction industry.

The European Directive 2014/24/EU aims to increase the efficiency of public expenditure and presents the LCC as a cost-effective approach to make recognizable the most economically advantageous tender, between the alternatives for the same public contest (Directive; 2014).

ISO 15686-5 (2008) contains guidelines for the application of LCC analysis of buildings and their components. This normative document refers the requirements which are needed for a grounded analysis, among which we have the three dimensions of building sustainability: economic, environmental and social aspects (ISO 15686-5; 2008).

On a European context, the EN 15643-4 (2012) forms part of a series of European Standards that provide a system for the sustainability assessment of buildings using a LCC approach. This standard provides specific principles, requirements and guidelines for the assessment of the economic performance of a building, taking into account the technical and functional characteristics of the building. The assessment of the economic performance of a building shall measure quantifiable economic aspects and impacts of the building. The economic indicators established to describe the economic performance are cost and financial value (EN 15643-4; 2012).

Finally, in 2015 the EN 16627 was published in order to provide calculation rules for the assessment of the economic performance of buildings. This standard is intended to support the decision-making process and documentation of the assessment of the economic performance of a building. EN 16627 complements the framework of EN 15643-4 (EN 16627; 2015).

The present document aims to promote the LCC application and verify the feasibility of the normative requirements about economic performance of buildings. For this purpose, a cost funding model, to assemble life cycle costs, is presented in the next section and intends to accomplish the assessment of economic performance of buildings, according to EN 15643-4 and EN 16627. In section 4 a case study is developed, in section 5 the results are discussed and section 6 contains the main conclusions achieved and future developments.

3. Cost Funding Model (CFM) of Life Cycle Costs

The European Standards EN 15643-4 and EN 16627 were chosen to build the Cost Funding Model (CFM) because they are the most recent normative documents related to economic performance. The model intends to simplify the assemble of the different life cycle costs involved in a building. The CFM is organized in information modules corresponding to the different life cycle stages. Each stage has cost categories that are discriminated in cost types. These categories and costs are proposed with an additional attention to their presence in at least one of the two European Standards, to follow what is already published.

EN 15643-4 is focused on the assessment of the economic performance of buildings, addressing LCC and other economic aspects, all expressed through quantitative indicators and taking into account the technical characteristics and features of the building. This standard is the framework for evaluation methodologies to be applied and it applies to all types of buildings. This framework is particulary relevant for the assessment of the economic performance of new buildings over their life cycle, and of existing buildings over their remaining service life and end of life stage. The assessment includes only the economic aspects of a building related to the built environment within the area of the building site.

The economic indicators to the economic performance are the cost and financial value. These indicators are represented in two approaches to carry out the economic assessment. The followed approach is the one that expresses economic performance in terms of cost over the life cycle. In this concept, the “lowest LCC” building over its life cycle is the most economic one. This implies that the building variants do not differ with regards to their functionality nor with any income streams produced by the building. In this approach only cost data needs to be gathered (EN 15643-4; 2012).

The standard EN 16627 complements the framework provided by EN 15643-4. The purpose of this standard is to provide calculation rules for the assessment of the economic performance of buildings. This standard specifies methods and rules for calculating cash flows over the LC of buildings, based on LCC analysis. The calculation rules can be applied to any type of building.

This standard indicates the Net Present Value (NPV) as a measure used in an LCC analysis. When only costs are taken into account, the NPV may be called the Net Present Cost (NPC), which is the one taken into account in this case of study. To calculate NPV/NPC it is necessary to specify the discount rate that is to be used for the calculation. But first, the value of the different items of the economic assessment shall be calculated without any discount rate and only when the assemble of costs and its time occurance is done may that rate be applied.

CFM follows the modular structure proposed in the two standards that is illustrated in Figure 1.

COST FUNDING MODEL OF LIFE CYCLE COSTS				
STAGE		**CLASS**		**COSTS**
BEFORE USE STAGE	**PRE-CONSTRUCTION**	**A0**	*Land*	A0.1 - A0.3
	PRODUCT	**A1**	*Material Supply*	A1.1 - A1.3
		A2	*Transport*	A2.1 - A2.3
		A3	*Manufacturing*	A3.1 - A3.3
	CONSTRUCTION PROCESS	**A4**	*Transport*	A4.1 - A4.5
		A5	*Installation process*	A5.1 - A5.17
USE STAGE	**USE STAGE**	**B1**	*Use*	B1.1 - B1.6
		B2	*Maintenance*	B2.1 - B2.10
		B3	*Repair*	B3.1 - B3.4
		B4	*Replacement*	B4.1 - B4.5
		B5	*Refurbishment*	B5.1 - B5.7
		B6	*Operational energy costs*	B6.1 - B6.8
		B7	*Operational water costs*	B7.1 - B7.7
AFTER USE STAGE	**END OF LIFE STAGE**	**C1**	*Deconstruction*	C1.1 - C1.6
		C2	*Transport*	C2.1 - C2.4
		C3	*Waste processing for reuse, recovery or and recycling*	C3.1 - C3.5
		C4	*Disposal*	C4.1 - C4.4

Table 1: Modular Structure to the Cost Funding Model of Life Cycle Costs

The life cycle of a building is divided into 3 stages: before use stage (modules A0 to A5); use stage (after delivery of the building: modules B1 to B5 not related to the building in operation and B6 and B7 related to the building in operation); after use stage or end of life (modules C1 to C4). The different stages have been divided into categories - which correspond to the indicated modules - and these, in turn, are discriminated in cost types. Cost types are meant to clarify which costs are included in each category. The CFM is presented in Figure 1 (next page), whose images are ordered from the first column from top to bottom, to the second column from top to bottom.

4. Case Study: Application of Cost Funding Model

The case study intends to test the validity of the proposed model - applicability and limitations - and its potential to support decision making. The application of the MCC is not intended to fill the full costs of different categories, but to analyse which costs it is possible to fill with the existing data. This objective is justified by the fact that the documented information about different buildings does not correspond with the organization of the proposed model. The application adjusts to the available data, not including estimation of costs through statistical analysis.

The study of LCC of construction focuses on a sample of school buildings. The existing data provided by Parque Escolar, E.P.E. (Public corporation) allowed the filling of rehabilitation schools costs in the LCC. The remain research proceeded in order to achieve a well-documented sample - that can be studied as an example of implementation of the refered model - trying to find the missing values. The values of the second research refer only to construction costs of the initial school buildings. These costs were collected from the Ministry of Education.

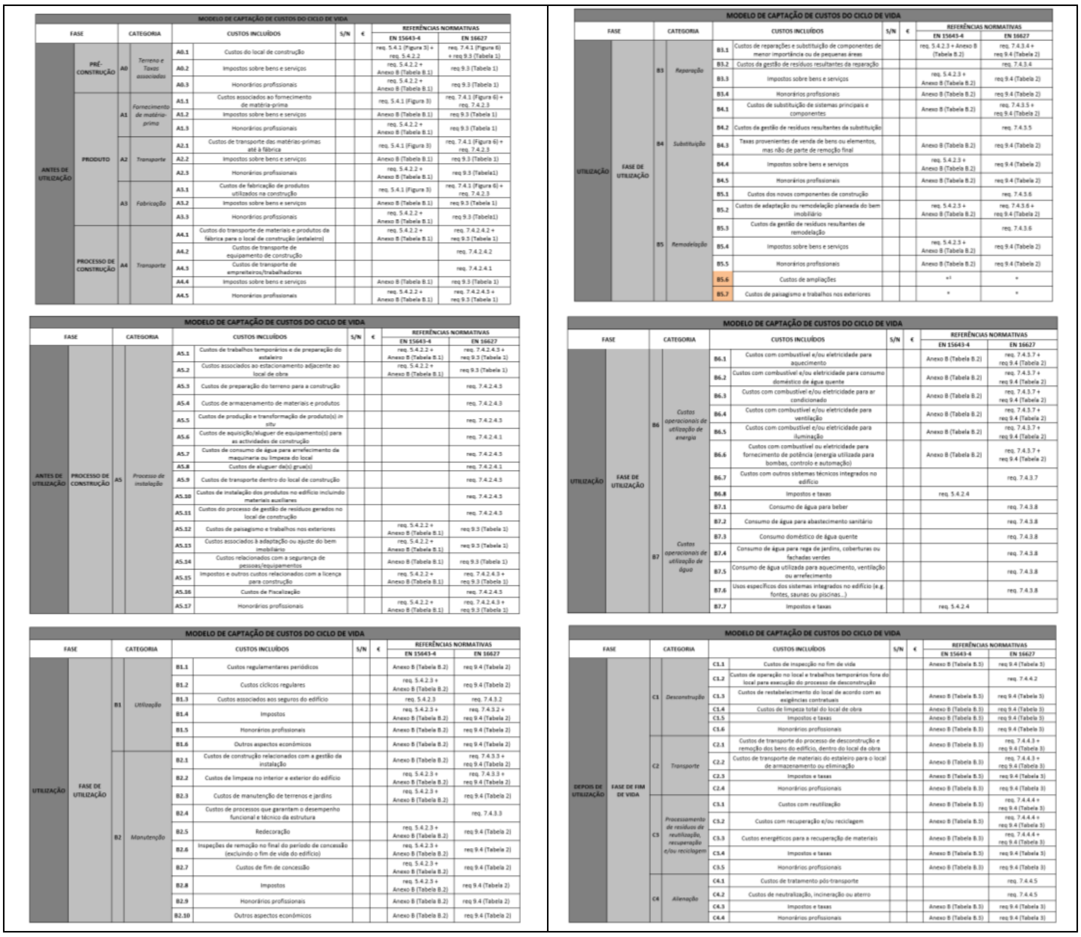


Figure 1: Model Structure of Life Cycle Costs

Sample Characterization

In the context of the School Modernisation Program, the ProNIC project (Protocol for the Standardization of the Technical Information of construction) was a computer application with great relevance for interventions that have occurred in this program. In ProNIC , the rehabilitation costs of different school buildings were documented and filed. The selected sample for the application of the CFM consists in a set of 7 schools, belonging to the 2nd portuguese school network construction period (since 1936 to 1968) and incorporated in said Modernization Program Phase 2. Thus, all schools analyzed have recently undergone rehabilitation interventions.

The schools' disclosure (name and county) which the collected costs refers to is confidential and therefore they are numbered from 1 to 7 and their data are presented with exclusive reference to the identification number, known as E1, E2, ... E7. However, it is allowed to indicate the location of the schools, which are located between the districts of *Coimbra, Leiria, Lisboa, Santarém* and *Guarda*.

The investigation started with a sample of 24 schools of the 2nd phase of the modernization program, whose data on rehabilitation interventions are stored in ProNIC and were provided by Parque Escolar (PE). However, in the next step of the investigation in the Ministry of Education, for the collection of the missing data, the sample was restricted. The reduction of the sample was necessary to examine cases that were complete as much as possible – according to the desired and available information - looking for a solid sample for the critical assessment of the application and usefulness of the CFM.

Almost all schools in the sample had a rehabilitation intervention with the recovery of what existed as well as new construction works. The distinction of this information is relevant to the correct filling of CFM because these costs belong to different categories of the model. In the treatment of the collected information it is considered that a rehabilitation intervention covers extension (new construction) and refurbishment (recovery of existing building). The choice of these nominations is due to the designation adopted in the CFM.

Table 2 presents the schools and their respective blocks, identifying the number of the refurbished blocks/buildings and the number of blocks built from scratch (belonging to the extension).

Table 2: Schools and blocks subject to the School Park Modernization Program

School		**E1**	**E2**	**E3**	**E4**	**E5**	**E6**	**E7**
Blocks	**Refurbished**	3	2	3	6	7	5	8
	New	2	4	1	2	4	-	2
Construction Site (Y/N)		Y	Y	Y	Y	Y	Y	Y
Outer (Y/N)		Y	Y	Y	Y	Y	Y	Y

Updating Collected Data

To gather the desired costs, it was taken into account that the value of money changes over time. At the present time a certain sum of money has a greater value than the same amount in the future due to the purchasing power of that amount in that time interval (Langdon; 2007). So, considering this purchasing power of money, it was recorded in the data survey not only the value of the costs but also the date of its occurance.

The comparison between costs occurred in different time frames requires the application of a discount rate. Discount rates reflect the time value of money. Its application converts the cash flows occurred at different time periods to a common time reference, usually the present time. The specification of the discount rate has a great influence on the calculations' outcome.

Accordind to the EN 16627, NPC is a normative measure used to determine and compare the cost effectiveness of different proposals. EN 16627 indicates that for the purposes of comparability the NPC shall be undertaken with a real discount rate of 3% (EN 16627; 2015). NPC brings future costs for the present time and its value is the sum of discounted future costs. In the existing buildings NPC is used to estimate rehabilitation costs and in new buildings NPC is used to estimate all the costs that arise from there. However, the NPC's application in this article follows a different purpose. The studied sample refers to existing buildings that had already suffered rehabilitation interventions and the aim is to fill the CFM with the real costs incurred, discounted to present time. So, the collected past costs will be "brought" to the present time. Therefore, the intended approach is the reverse of the calculation formula presented by the standard. This means that the reverse calculation formula will take place in this case of application, which results in:

$$\boldsymbol{Y_{CAL}} = \frac{\mathbf{1}}{\boldsymbol{X_{CAL}}} = \sum_{n=1}^{p} \frac{C_n}{q} = \sum(\boldsymbol{C_n} \times (\mathbf{1} + \boldsymbol{d})^{\boldsymbol{n}}) \qquad (1)$$

Where: ***Cn*** is the cost in year n; ***q*** is the discount factor; ***d*** is the expected real discount rate per year;
n is the number of years between the occurance of the cost and the base date; ***p*** is the period of analysis

The discount rate used is 3% and it is the expected real discount rate per year (***d***).

5. Results

Construction's costs and Rehabilitation's costs

The data collected for the construction stage were provided by the Ministry of Education and allowed the filling of category A5 from CFM (Installation Process). This category includes 17 types of costs, of which only 4 were possible to discriminate. These four types of costs are: A5.9 - transport costs within the construction site + A5.10 – costs from product installation into the building including ancillary materials; A5.16 - oversight costs and A5.17 - professional fees. The remaining costs were compiled into a generic category A5.

The non-discrimination of the different types of costs within the category A5, results from the mismatch between the information framework on file and the proposed organization in the CFM and the difficulty to match these two types of structured information. However, the fact that there are different types of costs unfilled is not a limitation of the CFM or an information gap in this category, because the total (real) value from category A5 is achieved and it will be that value which will make it possible to further the LCC analysis.

The details searched and analyzed with the CFM, go beyond the level of detail that is required in the standards, but it is not in vain. This level of detail may be interesting for two types of research: one is to achieve a thorough analysis' in order to save everything that is possible to save and find out which are the specific costs from alternative solutions that differentiate the total results; the second aim is to have in the CFM types of isolated costs, which have not only an economic concern but also an environmental concern (for example, the costs of production and processing products *in situ* - A5.5 - and the costs of waste management processes of wastes generated on the construction site - A5.11).

In the first analysis where the specific costs differ between alternatives, the relevance of knowing the values (orders of magnitude) in each type of cost is quite significant because when these values are updated to the reference date (the present year) they can reach values about 4 to 5 times higher than the initial costs (in this particular case of study when the dates on which the costs took place are consided). The farther the date of construction compared to the present year, the greater the difference between the real cost occurred and the same cost updated. The same difference between initial costs from different alternatives and the same costs after being updated may be much more significant in the updated comparison and therefore results in a considerable discrepancy between the LCC values from the analysed solutions, which can not be ignored.

For the rehabilitation stage, the collected data was provided by Parque Escolar and filled the category B5 (Refurbishment) of CFM. Despite the normative designation, this category refers to the rehabilitation costs, which encompasses both refurbishment and extension costs.

By filling the B5 category, the total compatibility between the collected data and the types of costs belonging to the B5 category was possible, avoiding the need for a generic category B5. However, the complete compatibility between the information provided and the CFM does not imply the filling of all types of costs in this category. It was possible to fill in only 4 of the 7 types of costs presented: B5.2 - adaptation or planned refurbishment costs of the existing building; B5.3 waste management costs resulting from refurbishment; B5.6 - expansion costs and B5.7 – landscaping and external work costs. The types of costs that remained unfilled are distributed by the types of costs filled. It is not possible to dissociate each other, because of the way that the information provided is organized.

In Figure 2, it is presented, for each school, the percentages of the collected costs for the construction (A5) and rehabilitation (B5) stages, discriminated in the types of costs belonging to CFM. To support these results, it is also presented Table 3. With regards to the results, it is important to note that percentages equal to zero does not mean that there are no costs for this category, it means that the cost expression for that value is so low face to the other that it obtains a near-zero result.

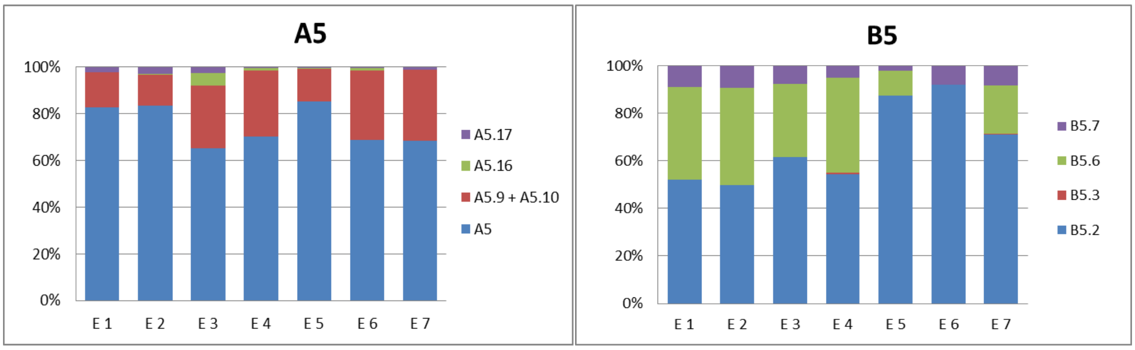


Figure 2: Percentages of Total Costs from construction (A5) and rehabilitation (B5) categories in CFM [%]

Table 3: Percentages values of Figure 2

Updated Costs of Construction Stage (%)							
	E1	*E2*	*E3*	*E4*	*E5*	*E6*	*E7*
A5	83	84	65	70	85	69	68
A5.9+ A5.10	15	13	27	28	14	30	31
A5.16	0	0	5	1	0	1	0
A5.17	2	3	3	1	1	1	1
TOTAL	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Updated Costs of Rehabilitation Stage (%)							
	E1	*E2*	*E3*	*E4*	*E5*	*E6*	*E7*
B5.2	52	50	61	54	87	92	71
B5.3	0	0	0	1	0	0	0
B5.6	39	41	31	40	11	0	20
B5.7	9	9	8	5	2	8	8
TOTAL	**100**	**100**	**100**	**100**	**100**	**100**	**100**

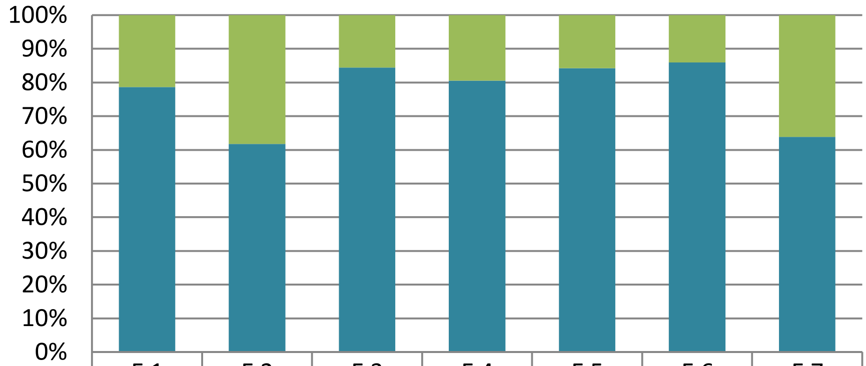
In construction costs, it is possible to conclude that for the most of the collected costs a discrimination in CFM's type of costs was not possible (65% to 85%) and also that there is a significant percentage allocated to transport and installation (A5.9+A5.10) between 14% and 31%. In rehabilitation costs, the highest percentages correspond to refurbishment (B5.2). For the expansion cost (B5.6) there are also significant amounts, between 11% to 41%. Also, 4 of the 6 schools with expansion works have a percentage greater than 30%.

The collection and analysis of gathered costs aims to achieve, as far as possible, reference values (value ranges), which do not yet exist in the standards. For this purpose, it is important to take into account the influence of the analysis period (in this case, all LC) and the discount rate (3% as stated in EN 16627) for the results.

To enable the comparative analysis between schools other indicators were analyzed, together with the updated total costs. Among these we have the school's area and the number of students. It should be noted that these values are not proportional between them, which means that the school with the smaller area does not necessarily have the lowest number of students. The analysis of these indicators shows that in some of the schools, a high total investment is diluted by the number of m^2 that the school has or by the large number of students that it will accommodate. These indicators enrich the evaluation of the LCC for each school, which leads to a more informed decision making process by checking which are the long term economically viable alternatives.

With the available data it was also possible to analyze, for each school, the evolution of the construction stage costs over the time that the construction lasted and the percentage's ratio between the construction costs and the rehabilitation costs of the schools. The first analysis allowed us to verify that the evolution of the constructions costs in average, for this school sample, is similar to the expected theoretical results. The second analysis enabled the finding that, for rehabilitation interventions occurred after 40 to 50 years of maintenance, the rehabilitation costs will be between 10% to 30% that of the construction costs. This range of values is wide, but it is still proved and therefore provides reference values (still missing in the normative documents). It is proved that a large number of years with maintenance actions does not necessarily correspond to a higher percentage of construction costs (representing the rehabilitation costs), which leads to the conclusion that the quality of maintenance actions influence the later rehabilitation's costs. Good maintenance will lead to lower rehabilitation costs, but this statement can only be demonstrated through an analysis over the maintenance costs of the schools.

In an overview of all the retrieved costs, Figure 3 presents the percentages distributed by the construction and rehabilitation stages. The E2 and E7 schools, having a more significant expression of rehabilitation's costs, suggest that there may have been an expansion and/or maintenance intervention of the existing buildings with a poor quality as the rehabilitation costs are related with the maintenance performed.



	E 1	E 2	E 3	E 4	E 5	E 6	E 7
% REABILITAÇÃO	21%	38%	16%	19%	16%	14%	36%
% CONSTRUÇÃO	79%	62%	84%	81%	84%	86%	64%

Figure 3: Percentages of total purchased costs

Viability of CFM

With this case study it was possible to realize that the CFM is feasible, which therefore means that the European standards are applicable, and to discover its advantages and disadvantages.

Advantages: Application of European Standards; Structure suitable to all building types; Homogeneos collection and filing of the information (incurred costs); Common basis for the generation of knowledge through estimates that are transformed into information (future costs); accessibility of information to all actors involved; Ease in the information consultation (computerized); Promotes decisions with quality (and quickness).

Disadvantages (improvement points): Types of costs unclear as to their content (more applications needed); lengthy process of filling (when the information available is not computerized); support structure needed for collecting information when it is not computerized.

6. Conclusions and future developments

Conclusions

The correct management in the AEC industry will always be a necessary work and concern. The art to get in this sector a saving that can be equivalent to the high costs involved is not linear, making it possible, in order to address this issue, the *continual improvement* - the last of the requirements set by the ISO 55001 standard for AM - by acquired experience.

The construction of CFM, besides its regulatory contribution, brings other advantages: a common basis that is applicable to any building; makes the information available to the different stakeholders involved (promoting good communication); allows the homogenization of the collection and storage of the information; discriminates the different stages that constitute the building LC, explaining which are the different costs that each stage involves; promotes the control and the estimation of the future costs (to maximize the use of the building and realize its maximum value); identifies which cost types are the most significant costs to the global LCC value; simplifies the quantification of LCC value providing robust levels of comparative analysis; and with all these points, it supports the decision making process with swiftness and quality.

Another contribution achieved with the CFM is that it gathers, in its framework, some types of costs with not only economic but also environmental relevance.

The standard structure of CFM facilitates its filling and becomes accessible to the different stakeholders. However, the application carried out shows that the accessibility becomes more obvious in cases where the information filed does not exist (and is filed directly in the proposed structure) than when information exists in an archive and it is needed to get a correspondence between the two information structures. The application concluded that the filling of the model with existing information depends on the information available and how is it filed.

With the analysis of the outcomes achieved with the CFM application it was possible to conclude that it is feasible not just the applicability of the model but also, and above all, the applicability of the normative requirements related to the assessment of the economic performance of buildings. The outcomes show that the overall picture of the costs enriches the information to any decision making process. Therefore, the perspective of the total costs involved with each school allows a more informed decision, with economic benefits in a long term.

About the collection of incurred costs (existing buildings) it was found that the process of matching the different ways to file information could be initially slow, but this work only takes place once and can offset the gain that is achieved with the global vision of the costs. Companies usually have some kind of record of its costs and even when that record has a detail that is more accounting instead of addressed to the AEC industry concerns, this matching is not impossible. This kind of work will help the company to achieve its future budgets, taking into account that a company, even if the business area is not related to real estate, will include in its budget (annual, for example) a significant part with the maintenance of the real estate the company owns and / or might include a new investment in another property.

With the outcomes' analysis it was concluded that: the majority (65% to 85%) of the collected costs of the construction stage was difficult to breakdown by the proposed types of costs in CFM; the use of different indicators (€ / m^2 and € / student) leads to different conclusions when comparing alternatives, stressing the relevance to consider more than an indicator for the LCC analysis; the sample's analysis allowed to achieve a range of reference values, considering that rehabilitation occurred after 40 to 50 years of maintenance stage will have a cost between 10% to 30% of the construction costs. Although the range of values is still imprecise, the application to a a major number of case studies and a full filling of the CFM will lead to reference values very useful to the future that, for now, are still lacking in normative standards.

Between different solutions for the same purpose, the lower value of LCC presents the most economically viable proposal. However, it must be borne in mind that not all customer's requirements will be purely economic, and that LCC is only one indicator (one of the most significant) for the decision. Thus, different customer's purposes will consequently lead to different values of LCC. The full filling of CFM, after updating the different costs involved, returns the LCC value of a building. In this case study, however, the information gap on the operation and maintenance costs does not allow the LCC value for each school to be fully realized.

The filling of CFM promotes the planning of the decisions related to constructed buildings or buildings to be constructed. The application of CFM if used since the early design of the building and filled with estimates of the costs arising since then, is a very interesting tool to represent the major saving potential. The model is a first step towards the LCC analysis, whose continual improvement is necessary for the companies and for the AEC industry.

Future Developments

For future work it would be interesting to complete the information of the sample, filling the CFM at all stages of the LC for a more complete and reliable analysis of its applicability. This will also promote a more accurate discrimination of the types of costs of each category and to achieve the range of reference values for further analysis.

Other case studies that may be developed: the analysis of buildings to be constructed by applying and examining cost estimates; the study of parts of LC analysis, in particular, the maintenance stage; creating a software that integrates the model and extend it to the application of infrastructure, enabling a precise monitoring of the costs, through charts and graphs illustrating the differences between the estimated and real values of costs; risk analysis of LCC analysis, following the requirements of the standards and increasing the reliability of the results obtained; analyze the other aspects of sustainability, environmental and social, in order to complete the sustainability assessment; analysis of LCC, considering the revenue; and finally analysis of the other categories belonging to Whole Life Cycle Costs (WLCC), which includes not only environmental and social aspects but also the non-construction costs.

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