# Performing life-cycle cost analyses of buildings: A supporting tool for asset management

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**Abstract**

Nowadays life cycle costing is becoming a significant decision tool to support decision making, designated as key element to improve construction competitiveness. Recently the international standard ISO 55000:2014 and the European Directive 2014/24/UE were published, these two publications are bringing out the concept and inspiring the study and development of new ways to ease life cycle costing practice. Despite the fact that potentialities had been identified, the implementation still be a challenge, on this paper a methodological approach is being developed according to international and European standards. The case studies have been assembled in order to test and validate the feasibility of the presented methodology.

## 1. Introduction

Life cycle cost (LCC) is the decision objective of many engineering problems such as project selection, product design and so forth.

The term LCC became popular in the sixties, it was during this time that some people began to ask the reason that decision making was merely based on acquisition costs. Since then, a whole new concept in construction industry began to appear. Its development involved gradual changes, comprising key stages of the life cycle of any constructed asset. The concept is currently gaining grounds on traditional cost accounting approaches and a number of publications have discussed the features of LCC concept.

In 2008 an international standard (15686-5:2008) was published by ISO, that is the context in which an agreement about LCC definition was reached within the scientific community. This publication describes LCC as the cost of an asset or its parts throughout its life cycle, while fulfilling the performance requirements. The same document 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.

On the other hand, a brief explanation about asset management (AM) concept is required in order to provide a clear understanding of the thesis' scope. People have been managing assets for thousands of years, however a whole new concept appeared in 2004 with BS PAS 55. This document provided clear definitions and requirements specifications for establishing and verifying a joined-up, optimized and whole-life management system for all types of physical assets. Recently, relating to the same subject matter a family of standards ISO 55000 were published by ISO. Thereupon, asset management was defined as the coordinated activity of an organization to realize value from

assets. This activity can also refer to the application of the elements of the asset management system. As an add-on to the definition, realization of value normally involve a balancing of costs, risks, opportunities and performance benefits. Such publications highlighting the benefits of effective and efficient management of assets are the reason why asset management is one of the most popular topics in 2014.

## 2. Legal and Regulatory Framework

LCC is high on the political agenda at the moment, resulting in the new public procurement directive, 2014/24/UE where the big news is the introduction of LCC which should cover all relevant parts of the life cycle product, service or contract to purchase. Furthermore the new asset management related standards focused attention on the use of a life cycle management approach to realize value from assets.

This methodology is intended to be compatible with ISO 15686-5 which is currently at the DIS ballot stage (ISO/DIS 15686-5:2014). LCC analysis as an input to asset management activities is noteworthy enough to be mentioned among several clauses technically revised in this second edition.

For all that has been said above, it might be clear that LCC constitutes an important tool for asset management within the construction sector.

Regardless of LCC's great potential in most of the cases LCC calculations has not yet been achieved as an integrated part of construction projects. However the new legal and regulatory framework (ISO/DIS 2014, 2014/24/UE, ISO 55000:2014) spurred the development of methodologies that simplify LCC practice.

This paper aims to make LCC's advantages widely known, with look ahead enhancements to improve efficiency of buildings costs planning. Hence, a methodology approach is presented for getting over adversities and constitute a useful instrument for construction stakeholders as project owners, contractors or clients (either private or public).The outline of the rest of the paper is as follows; in the next section we look at LCC methodical approach that have been developed. In section 4 case studies features are presented, section 5 the various results are discussed, section 6 contains a summary of the main conclusions achieved in this paper.

## 3. Methodology for LCC analysis

This document, provides a methodological framework for consistent application of LCC, it identifies the key considerations to be taken into account, at each stage, in the LCC process and provides a practical guidance on the application of LCC. The methodology was specifically designed for collect relevant information, which supports LCC analysis. There are two broad categories of information, client's requirements and asset's characteristics. The different purposes for which LCC may be employed, and the different stages of asset life cycle at which it is used, imply the need for different levels of detail and accuracy in the process. Then, as a first step, client should state very clearly the purposes of the LCC analysis. On the other hand, key features of the asset in question (project constraints, physical and functional characteristics) exert a powerful influence on LCC results, so they also need to be very thoroughly analyzed.

The methodology consists of 12 steps, 30 objectives and 24 tables, guiding the user through a series of numbered steps that follow a logical train of thoughts as shown on the diagram included in figure 1. Each steps contains the objectives for the tables. Filling the information contained on each table assumes that the user gathers all the necessary information. Setting goals for each step should help the user accomplishing a reliable analysis and constitute a useful way to organize ideas. The objectives proposed for each step are listed in table 1.

These tables should assist the user to carry out LCC analyses, for which they are intended to provide users a technique conceptually and practically simple. This technique, should also be in accordance with reference standards and contribute to data management during the project life cycle used, that contributes to assess the economic performance of buildings using quantitative indicators and support subsequent decisions.

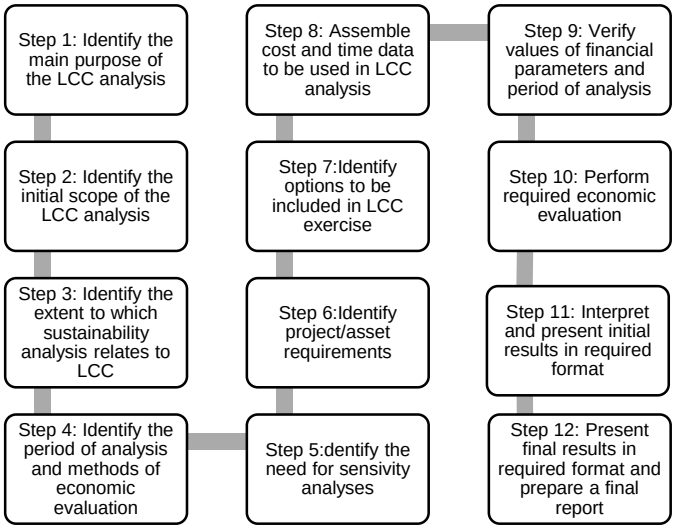


*Figure 1: Methodology diagram*

The publication/standards that have backed methodology tables are shown in table 2. Table 2 also points out the important influence of Langdon's and ISO 15686-5 publications for the methodological approach. From step 1 to 8, the users are expected to collect all inputs that henceforward are used to perform LCC analyses and compile the required outputs. This step-by-step methodology follows a logical line of thoughts that leads the user to a better understanding and attain desired outcomes. Since it's not possible to demonstrate 24 tables in this paper, the aim is to show the overall picture with few tables that are an integrating part of the methodology. As can be seen in figures 2,3,4 and 5 it's possible to adapt the table's structure to a data management system. All in all the methodology assists the user summarizing important information and dealing with a whole new concept.

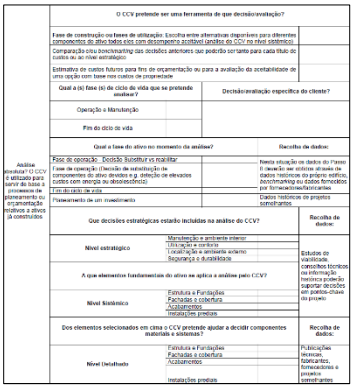


*Figure 2: Step 1 Table 1 - purpose of the LCC analysis*

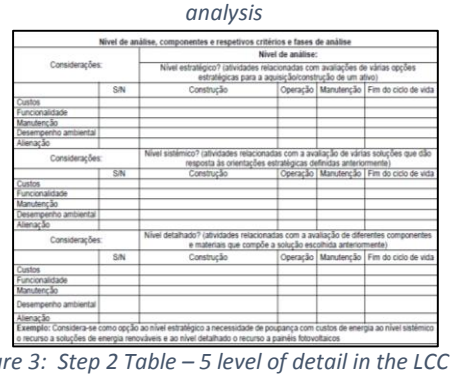


*Figure 3: Step 2 Table – 5 level of detail in the LCC analysis*


*Figure 4: Step 6 - Identify asset requirements (functional characteristics)*

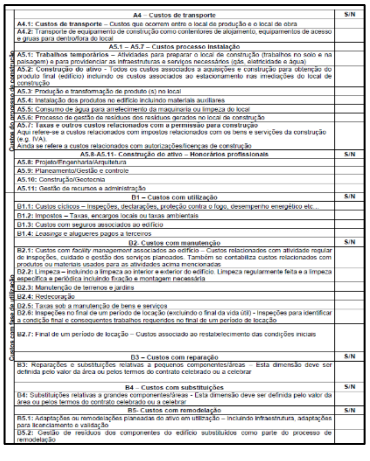


*Figure 5: Step 8 – Table 16 assemble cost data to be used in LCC analysis*

*Table 1: Overview of steps (adapted from Langdon, 2007)*

| Step | Table number | Objective |
|---|---|---|
| **1** | 1,2 | Develop a clear statement of the purpose of the proposed LCC analysis |
| | | Understand of how LCC analysis can be appropriately and successfully applied and the outcomes that can be expected |
| **2** | 3,4,5 | Develop a clear understanding of the scale of application |
| | | Clear understanding of the stage(s) of the project or asset life cycle over which it is likely to be undertaken |
| | | Understand the scope and nature of the issues and information likely to be relevant |
| | | Understand any specific client reporting requirements |
| **3** | 6 | Understand the extent to which the outputs of sustainability assessment will form inputs into LCC analysis (direct costs) |
| | | Understand need to assessing environmental impact (LCA) |
| **4** | 7 | Identify and confirm with the client/stakeholders the period of analysis and the considerations governing its choice |
| | | Identified and confirmed with the client the appropriate techniques for assessing investment options including the discount rate to be used |
| **5** | 8,9 | Identify the need for sensitivity analyses |
| | | Identify key input values about which there is uncertainty and trial scenarios |
| **6** | 10,11,12,13 | Identify the intended functions and characteristics of the asset |
| | | Develop a statement of project constraints |
| | | Define all relevant performance and quality requirements |
| | | Confirm all the previous options |
| **7** | 14 | Select one or more alternative options for the asset to be analysed |
| | | Fill in the presented table (Table 15) |
| **8** | 15,16,17 | Identify all cost relevant to the LCC analysis and made the best estimate for the value of each cost |
| | | Identify the time related data for each cost |
| **9** | 18,19,20 | Confirm the period of analysis |
| | | Confirm the values for the relevant financial parameters |
| | | Consider whether taxation issues should be accounted for in the analysis |
| **10** | 21,22 | Draw together the various cost and time data and analysis parameters |
| | | Perform the LCC analysis |
| | | Record the results for interpretation |
| **11** | 23 | Review and interpret the initial results of the LCC exercise |
| | | Present these results to the client for discussion using appropriate formats |
| | | Identify whether further iterations are required |
| **12** | 24 | Provide a final report in accordance with Req. 9 ISO 15686-5 setting out the conclusions drawn from the LCC exercise in response to its defined objectives |

*Table 2: Publications for methodology steps*

| Passos | Publicações | | | | |
|---|---|---|---|---|---|
| | Davis Langdon Consulting | ISO 15686-5 | pR EN 16627 | EN 15643-4 | AECI |
| **Passo 1** | ✓ | ✓ | | | |
| **Passo 2** | ✓ | ✓ | | | |
| **Passo 3** | ✓ | ✓ | | | |
| **Passo 4** | ✓ | ✓ | | | |
| **Passo 5** | ✓ | ✓ | | | |
| **Passo 6** | ✓ | | | | ✓ |
| **Passo 7** | ✓ | ✓ | | | |
| **Passo 8** | ✓ | | ✓ | ✓ | |
| **Passo 9** | ✓ | ✓ | | | |
| **Passo 10** | ✓ | | | | |
| **Passo 11** | ✓ | | | | |
| **Passo 12** | | ✓ | | | |

## 4. Case studies

The case studies have been assembled in order to test and validate the feasibility of the presented methodology. The practical application is illustrated with three case studies: an office building the Gebalis' headquarters, a hotel building owned by Hoteis Real group and finally Holliday Inn's hotel building. These case studies presented here are a sample from different organizations, covering different approaches to LCC and illustrating particular instances of using the methodology.

Gebalis hadn't a data base about costs, for the reason that the company made a research already focused on methodology instructions. In the first instance, Gebalis choose which costs categories were applicable to their building and then fill the cost values based categories previously selected. That's why in this specific case, a percentage of costs collect doesn't make sense. The building was constructed in 2000, however the company only moved to this building in 2005. Consequently, available that are from forward since 2005. Table 3 illustrates the main characteristics of case studies.

Once an initial LCC methodology has been generated it is needed to refine and adapt the model in consultation with the client. As certain statistical techniques might be required in order to get reliable forecasted costs, achieving a final value of LCC it's not the main purpose. That is why the methodology was adapted accordingly, this process might include minor changes such as ignore steps 5, 7, 9 and identify methods of economic evaluation of step 4 concerning the available data related assets already constructed.

The application was carried out filling tables in and checking whether aims and objectives were achieved. As a matter of fact, all objectives were accomplished excepting those related to costs forecasting. All the application results are illustrated along section 5.

## 5. Application outcomes

After applying the methodology to the three case studies, the results were carefully analyzed. The organization that is intrinsic to this methodology, favored the meetings with the different companies. It also allowed for improved communication and provided a better understanding from the client's side. As

shown in tables 4 and 5, the outcomes of application were quite good. With a high percentage of collected data, both in cases A and C. Besides, organizations recognized the methodological approach as an important process along with collected data. That was considered significant for the asset and organization and hence capable of sustain a LCC analysis.

Different outputs from a life cycle analysis could be expected, particularly cost profiles, where the impact of different items costs could be seen. This type of outcomes might be very important for management purposes, because it can provide an overview of the significant costs and identify in advance what is expected to happen. On the application several costs items collected throughout the period of analyses were plotted for each case study.. Hence, the outcomes obtained from the application seems to be very useful for AM, aligning the strategic asset management plan, for instance.

Taking into account the three LCC exercises, in any case energy consumption (B6), water consumption (B7) and facility management (B2.1) are a sizeable portion of the whole expenditures. Therefore, options that are likely to impact on that items should be done carefully. Hire and leasing charges (B1.4) along with end of lease expenditures (B2.6, B2.7) were not relevant in any of the three cases. Consequently, its relevance in future developments might be questionable. With the exception of few costs (*e.g.* Case A B1.3) the costs plot indicates a constant trend all over the period of analysis which makes sense as consequence of short time periods and recent assets. In order for high values of acquisition costs (case A and C) could be seen, chart 1 is presented in a logarithmic scale. Taking into account the three LCC exercises, in any case energy consumption (B6), water consumption (B7) and facility management (B2.1) are a sizeable portion of the whole expenditures. Therefore, options that are likely to impact on that items should be done carefully. Hire and leasing charges (B1.4) along with end of lease expenditures (B2.6, B2.7) were not relevant in any of the three cases. Consequently, its relevance in future developments might be questionable. With the exception of few costs (*e.g.* Case A B1.3) the costs plot indicates a constant trend all over the period of analysis which makes sense as consequence of short time periods and recent assets.

Table 6 sums parameters and values up for each LCC exercise. Analyzing LCCA total values it's possible to see that LCCA(C) > LCCA (A) > LCCA (B). This fact could be justified by the information relative to the client's requirements and asset's features collected through methodology process. Accordingly, parameters such as period of analysis, physical and functional features such as gross and window area, have direct impacts on operation and maintenance costs. Indeed LCCA value for each case as long with constant value in early years seems to be in accordance with presented parameters. Some functional and physical features are not presented in table 6, that doesn't mean that they are not important, although, they aren't different among the case studies, which is why under those circumstances it wasn't possible to assess their influence.

Chart 1 shows an overall picture of cost profiles in each case study. A detailed analysis of chart 1, identify a common trend, in other words in any case study the global costs decreases linearly until the first year and then achieving a specific value that remains constant all over the period of analysis. The cost profile related to case B reaches a peak in 2010, consequence of an investment in solar panels. Hence, in conclusion for the items presented, costs values shouldn't have big disparities all over the first 8 years of building life cycle.

*Table 3: Case Studies overview*

| Case study | Client's purposes | Type of building | Gross floor area ($m^2$) | Performance level | Period of analysis | Image |
|---|---|---|---|---|---|---|
| Case A: Holliday Inn | After 5 years exploiting the hotel building, minor costs related to small repairs and replacements start appearing. In order to judge whether initial options still correct and provide client more information about future investments a LCC analysis is performed. | Hotel, medium height (9<H≤28m) | 6.448 $m^2$ | Medium | 6 years |   |
| Case B: Gebalis' headquarter | Gebalis will have a large investment in renewing of their office building sooner rather than later. Requires an assessment of options made during early stages and search for an understanding whether these options were correct. Gebalis also seeks use LCC as an assessment criterion in their municipal *portfolio*. | Office, Low height (H≤9m) | 680 $m^2$ | Low | 9 years |  |
| Case C: Villa Italia | Due to huge portfolio managed by the group, is required a LCC analysis in order to get a reliable indicator that establishes a unitary measure of economic performance among assets. | Hotel, medium height (9<H≤28m) | 21.199 $m^2$ | High | 7 years |  |

*Table 4: Collect costs (Case A, B and C)*

| Collected costs | | | | | | |
|---|---|---|---|---|---|---|
| Life cycle stages | Case A | | Case B | | Case C | |
| Construction | 4.758.367,21€ | 86,5% | 72.374,60€ | - | 29.925.158,99€ | 80% |
| Operation and Maintenance | 1.491.667,00€ | 100% | 958.916,67€ | - | 208.625,82€ | 100% |
| End-of-life | 0,00 € | 0% | 0,00€ | 0% | 0,00€ | 0% |
| Total | 6.250.034,21€ | 55% | 1.031.291,27€ | - | 34.447.497,40€ | 82% |

*Table 5: Non-Collected costs (Case A, B and C)*

| Non-collected costs: Main reasons | | |
|---|---|---|
| Case A | Case B | Case C |
| Scope and nature of costs doesn't fit in LCC analysis (*e.g* salaries, breakfast, marketing…)<br><br>Some costs that weren't collected should in fact be in the methodology (insurances, occupational safety and health, technical installations) | Not-applicable | Scope and nature of costs doesn't fit in LCC analysis (*e.g* furniture, fixtures and equipment…) |

Other units of measure of LCCA are shown in table 6. The asset related to case B represents an office building, that's why it should not be comparable with the other two (A and C) that represents hotel building. These units of measure might provide an indicator that could be useful for assessing economic performance of comparable assets. Looking through table 6 the analysis outcome it's possible to see that LCCA/$m^2$ (C) > LCC/$m^2$ (A).

As a matter of fact, these evidences seems to make sense and are consistent with collected information related to assets features. Case C represents a luxury hotel that aims to provide a high quality service for their customers, which are reflected in high maintenance expenditures. Case A building only has 30% of total gross area of building case C, conversely both have the same capacity (300 costumers). Concerning that, hotel C comprises several facilities such as spa, gymnasium, swimming pool etc. In contrast, hotel A was planned for short term stays, providing costumers a business environment instead of holidays. Consequently, the information collected by methodology seems to have a strong influence on LCCA values.

*Table 6: Values of the outcomes*

| | **Parameters** | **LCCA:Case A** | **LCCA:Case B** | **LCCA:Case C** |
|---|---|---|---|---|
| Units of measure | LCCA Value | 6 250 034,21 € | 1 031 291,27 € | 34 298 049,50 € |
| | LCCA/$m^2$ | 950,36 € | 3 290,87€ | 179,64€ |
| | LCCA/occupier | 22 865,27€ | 64 000,00€ | 114 245,88€ |
| Analysis data | Period of analysis | 5 years | 9 years | 7 years |
| | Type of building | Medium height | Low height | Medium height |
| | Year of construction | 2009 | 2000 | 2007 |
| | Window area | 342 $m^2$ | 63 $m^2$ | 1054,5 $m^2$ |
| | Capacity (persons) | 268 | 20 | 300 |
| | Gross floor area ($m^2$) | 6.448 $m^2$ | 680 $m^2$ | 21.199 $m^2$ |
| | Performance level | Medium | Low | High |
| | Maintenance level | Medium | Low | High |
| Analysis outcomes | Cost items applicable | 30 | 25 | 34 |
| | % Total values collected | 55% | - | 82% |
| | Medium value in early years (Total) | 277 892,00 € | 87 000,00 € | 581 511,74 € |
| | Medium value in early years/$m^2$ | 105,60 € | 329,09€ | 179,64 € |
| | Medium value in early years/ Occupier | 2.540,59 € | 11 188,96€ | 12.693,99 € |

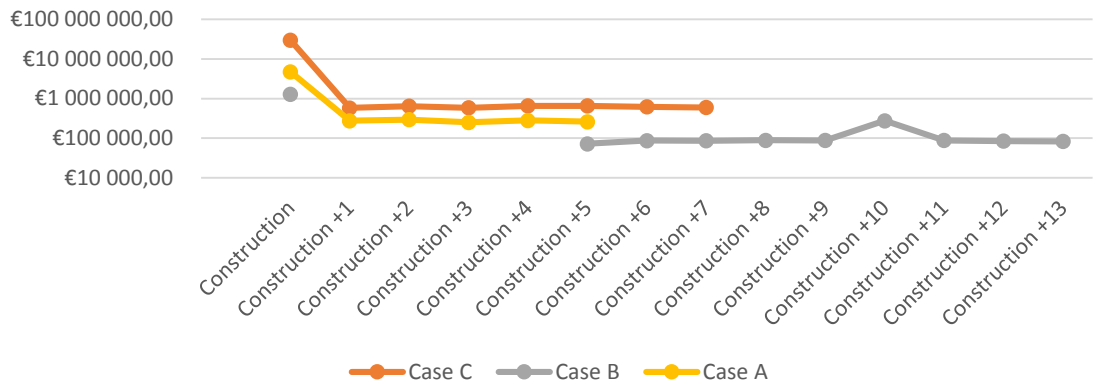


*Chart 1: Cost profile (Case A, B and C)*

**6. Summary and conclusions**

This paper can be summarized in the following four points

- **Methodology applicability**

The case studies provided a valuable experience about work with organizations. Methodology structure, also eased communication with clients about application expectations. Additionally, the same organizations recognized the information asked as relevant for LCCA value. Based on outcomes and on interactions with organizations we may conclude that the methodology presented is applicable.

- **Relevant data collected**

The high percentages of collected costs, might demonstrate that the methodology included information that is likely to have impact on assets' costs and performance. The LCC value in and of itself doesn't add up, indeed information methodology seems to explain LCC value describing key features of the asset under consideration and suits the client's particular needs and purposes coming along improvements in decision making tools.

- **Supporting other areas**

Whilst this methodology is concerned with the process of carrying out LCC analyses it's important to recognize that the process may not end with the final report. Some users may wish to control LCCA values, comparing real values with the predicted ones.

This methodology could constitute a useful tool for carrying out assessments of economic performance using a quantitative indicator according with EN 15642-4/pR EN 16627. This indicator taken together with ISO 55000 guidelines might strengthen asset management strategic approach.

- **Supporting forecasting techniques**

In any case study, cost items related to operations and maintenance stages kept up a constant trend over its period of analysis. It is also important to draw attention to the fact that identifying a standard cost profile over 8 years along with a recognized important information to be considered in LCC analysis, could constitute an important support for forecasting techniques. ~

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