

# LIFE CYCLE COST CALCULATION MODELS FOR BUILDINGS

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## ABSTRACT

Most commonly, production cost is the main cost factor in construction and is often set to the minimum, which does not necessarily improve the lifetime performance of buildings. However, a higher production cost might decrease total life cycle cost (LCC). It is important, therefore, to show the construction client in the early design phase the relationship between design choices and the resulting lifetime cost. Today, LCC calculation is used extensively for industrial products to minimise production cost and increase profit. Clearly, there are significant differences between an industrial product and a building from the life cycle perspective. The main differences are the life of a building and the lack of industrialisation in the building process, especially during construction. These factors make calculating LCC for a building difficult early in the design process. This paper presents a state of the art analysis in the area of LCC for construction. It offers a structural overview of theoretical economic methods for LCC analyses and their restrictions as described in the literature. The paper also reveals the primary data which are required to carry out a LCC analysis and discusses limitations in the application of life cycle costing from the client's perspective.

## 1. INTRODUCTION

According to Ozsariyildiz and Tolman (1998), the construction industry is facing increased demands from society. Construction clients ask for high quality building, lower cost and shorter lead-time. The clients, who have to pay the bill, have actually very little influence over time, cost and quality (Ozsariyildiz and Tolman, 1998). Buildings represent a large and long-lasting investment in financial terms as well as in other resources (Öberg, 2005).

In cold climate regions we spend a large amount of our time in buildings. The indoor environment of a building is therefore very important to us as it affects our well-being and health. Improvements of lifetime quality and cost effectiveness of buildings is consequently of common interest for the owner, the user and society. Life cycle cost (LCC) for buildings is therefore an important tool for involving the construction client better in early stage design decisions. However, regardless of its importance, life cycle costing has found limited application so far (Bakis et al., 2003).

An office building will consume about three times its initial capital cost over a 25 year period, but still far more attention is paid to the initial capital cost (Flanagan and

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Jewell, 2005). It should be considered that higher production costs can decrease the total LCC for a building. As stated by Kotaji et al. (2003) it is particularly important to show the relation between the design choices and the resulting lifetime cost (i.e. energy, maintenance, and operation cleaning) (Kotaji et al., 2003).

This paper presents a state of the art review in the area of LCC in construction. The aim is to describe the different advantages and disadvantages of the main theoretical economic evaluation methods for LCC calculation and show what relevant data and main sources are needed. Furthermore, the limited application of life cycle costing in the construction sector from the clients' perspective is discussed. The paper is structured as follows. First, the different definitions for LCC are discussed. In section 2.2 the different economic evaluation methods for LCC are presented and their different advantages and disadvantages are described. Section 2.3 presents the main data and data groups for life cycle costing. In Section 2.4 the main data sources are discussed. Section 2.5 refers to clients' limited request for life cycle costing so far. The research method is described in section 3. Results, implementation and exploitation are discussed in section 4. In section 5, the conclusions are presented.

## 2. LIFE CYCLE COSTING IN PERSPECTIVE

### 2.1. Definition of WLC, WLA and LCC

There are different terms used in the literature today like, "cost in use", "life cycle costs" (LCC), "whole life costing" (WLC) and "whole life appraisal" (WLA). Where (Flanagan and Jewell, 2005) defined that the terminology has changed over the years from "cost in use" to "life cycle costing" and further to "whole life costing". They defined the new term "whole life appraisal" which is globally used today and which contains consideration of the cost benefits and performance of the facility/asset over its lifetime.

The draft of the ISO Standard 15686-5 (ISO, 2005) instead makes a difference between the expressions WLC and LCC. Their contention is that WLC is equivalent to LCC plus external cost. Even there it is admitted that sometimes all terms are used interchangeably, but the ISO Standard does try to interpret those terms more narrowly. The Standard states that LCC should be used to describe a limited analysis of a few components where instead "life cycle costing" should be understood as the cost calculations themselves and WLC should be seen as a broader term, which covers a wide range of analysis. The Norwegian Standard 3454 (Ns, 2000) defined LCC as including both original costs and cost incurred throughout the whole functional lifetime including demolition.

Discussions about wording bring a lot of confusion in this field. In this article, LCC is used equivalent to WLC. LCC analysis is, in this context, to be understood as an analysis over the whole life cycle of a building. The term LCC is chosen as it is still the better known term today in practice.

### 2.2 Evaluation of LCC methods

The literature shows a broad variation of economic evaluation methods for LCC analysis. They all have their advantages and disadvantages. The methods have been formed for different purposes and the user should be aware of their limitations. The

reviewed literature is structured in table 1. The table illustrates the six main economic evaluation methods for LCC, their advantages and disadvantages and for what purposes they can be used. The literature shows that the most suitable approach for LCC in the construction industry is the net present value (NPV) method. Existing mathematical LCC models, which are based on NPV, have various advantages and disadvantages, as they differ in the breakdown costs elements. The model from the American Society for Testing Materials (eqn. 1) for example, distinguishes between energy and other running cost, which is useful in adopting different discount rates for different cost items.

$$NPV = C + R - S + A + M + E \quad \dots (1)$$

*C = investment costs*

*R = replacement costs*

*S = the resale value at the end of study period*

*A = annually recurring operating, maintenance and repair costs (except energy costs)*

*M = non-annually recurring operating, maintenance and repair cost (except energy costs)*

*E = energy costs*

### 2.3 Data required for life cycle cost calculation

The data requirements according to the reviewed literature for carrying out LCC analysis are categorised in figure 1. These different data influence the LCC in different stages of the life cycle.

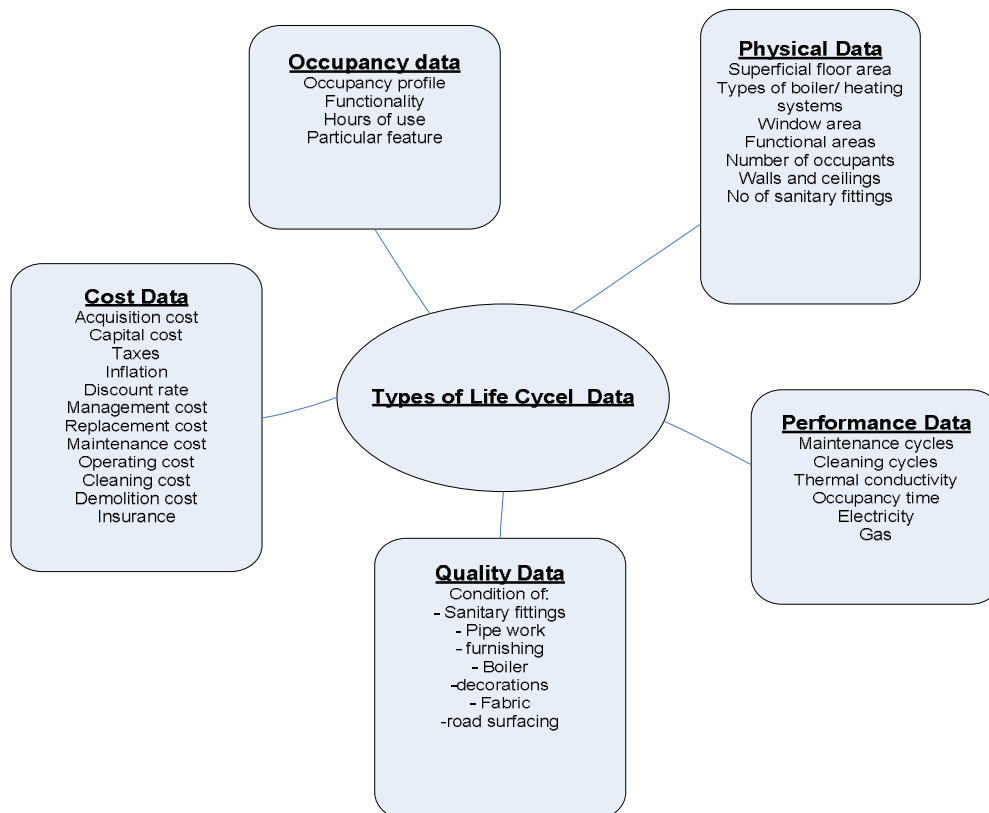


Figure 1. The required data categories for a life cycle cost analysis

Table 1. The advantages and disadvantages of economic evaluation methods for LCC

Method	What does it calculate	Advantage	Disadvantage	Usable for
Simple payback	Calculate the time required to return the initial investment. The investment with the shortest pay-back time is the most profitable one (Flanagan et al., 1989).	Quick and easy calculation. Result easy to interpret (Flanagan et al., 1989).	Does not take inflation, interest or cash flow into account (Öberg, 2005, Flanagan et al., 1989).	Rough estimation if the investment is profitable (Flanagan et al., 1989).
Discount payback method (DPP)	Basically the same as the simple payback method, it just takes the time value into account (Flanagan et al., 1989).	Takes the time value of money into account (Flanagan et al., 1989).	Ignores all cash flow outside the payback period (Flanagan et al., 1989)	Should be only used as a screening devise not as a decision advice (Flanagan et al., 1989).
Net present value (NPV)	NPV is the result of the application of discount factors, based on a required rate of return to each years projected cash flow, both in and out, so that the cash flows are discounted to present value. In general if the NPV is positive it is worth while investing (Smullen and Hand, 2005). But as in LCC the focuses is one cost rather than on income the usual practice is to treat cost as positive and income as negative. Consequently the best choice between tow competing alternatives is the one with minimum NPV (Kishk et al., 2003).	Takes the time value of money into account. Generates the return equal to the market rate of interest. It use all available data (Flanagan et al., 1989).	Not usable when the comparing alternatives have different life length. Not easy to interpret (Kishk et al., 2003).	Most LCC models utilize the NPV method (Kishk et al., 2003). Not usable if the alternatives have different life length (Flanagan et al., 1989).
Equivalent annual cost (ECA)	This method express the one time NPV of an alternative as a uniform equivalent annual cost, for that it take the factor present worth of annuity into account (Kishk et al., 2003).	Different alternatives with different lifes length can be compared (ISO, 2004).	Just gives an average number. It does not indicate the actual coast during each year of the LCC (ISO, 2004).	Comparing different alternatives with different life's length (ISO, 2004).
Internal rate of return (IRR)	The IRR is a discounted cash flow criterion which determines an average rate of return by reference to the condition that the values be reduced to zero at the initial point of time (Moles and Terry, 1997). It is possible to calculate the test discount rate that will generate an NPV of zero. The alternative with the highest IRR is the best alternative (ISO, 2004)	Result get presented in percent which gives an obvious interpretation (Flanagan et al., 1989).	Calculations need a trail and error procedure. IRR can be just calculated if the investments will generate an income (Flanagan et al., 1989).	Can be only use if the investments will generate an income which is not always the case in the construction industry (Kishk et al., 2003).
Net saving (NS)	The NS is calculated as the difference between the present worth of the income generated by an investment and the amount invested. The alternative with the highest net saving is the best (Kishk et al., 2003).	Easily understood investment appraisal technique (Kishk et al., 2003).	NS can be only use if the investment generates an income (Kishk et al., 2003).	Can be used to compare investment options (ISO, 2004). But just if the investment generates an income (Kishk et al., 2003).

The occupancy and physical data could be seen as the key factors in the early design stage. LCC estimation in this stage depends on data such as floor area and the requirements for the building. Flanagan et al (1989) stressed the importance of occupancy data as other key factors, especially for public buildings. Performance and quality data are rather influenced by policy decisions such as how well it should be maintained and the degree of cleanliness demanded (Kishk et al., 2003). Quality data are highly subjective and less readily accountable than cost data (Flanagan et al., 1989). In the more detailed design stage, life cycle cost estimation is based more on performance and cost data of a building (Bakis et al., 2003). Cost data are most essential for LCC research. However, cost data that are not complemented by other data types would be almost meaningless (Flanagan et al., 1989). These data need to be seen in the context of other data categories to obtain a correct interpretation of them (Kishk et al., 2003).

It should be considered that LCC is a decision making tool in the sense that it could be used to select among alternative projects, designs or building components. Consequently LCC data should be presented in a way that enables such comparison. For that reason the cost breakdown structure is an important concept for LCC (Bakis et al., 2003).

There are several different standards (ISO 15686-5/ NS3454/ ASTM/ Australian/ New Zealand-Standard) available to guide a LCC analysis. All have different cost categories and slightly different cost breakdown structures.

## 2.4 Main sources of data

There are three main sources for data for LCC purposes.

- from the manufacturers, suppliers, contractors and testing specialists;
- historical data; and
- data from modelling techniques.

Data from manufacturers, suppliers, contractors and testing specialists can often be seen as a best guess. They may have a detailed knowledge of the performance and characteristics of their material and components, but do not have knowledge of the ways in which facilities are used (Flanagan and Jewell, 2005). However, extensive knowledge and experience of specialist manufacturers and suppliers are a valuable source for life cycle information. If the required data are not available, modelling techniques can be used. Mathematical models can be developed for analysing costs. Statistical techniques can be incorporated to address the uncertainties (Flanagan and Jewell, 2005). Data from existing buildings are used as historical data. Some of them are published as the BMI (Building Maintenance Information) occupancy cost. Other sources include clients' and surveyors' records, and journal papers (Flanagan et al., 1989).

Thus, data collection brings difficulties; however, LCC analysis is only accurate if the collected data are reliable (Emblemsvåg, 2003). Existing databases have their limitation, they do not record all necessary context information about the data being fed into them (Kishk et al., 2003). The data are usually expressed as units of cost which limits them to local use.

## 2.5 Construction client

An office building will consume about three times its initial cost over a 25-year period (Flanagan and Jewell, 2005). Therefore, it can be essential for the construction client to use LCC as a decision making tool among alternative projects, designs or building components to reduce building running costs over the long term. Despite its importance, LCC has found limited application so far in the construction sector (Bakis et al., 2003).

LCC needs time and effort. For that reason, there has to be a clear output motive to use LCC techniques if it would be a worthwhile effort for the construction client (Raymond and Sterner, 2000). The availability of LCC data are today rather limited. One reason is the lack of any framework for collecting and storing data (Bakis et al., 2003). Construction clients often give a low priority to LCC as they are not aware of the benefits from it (Raymond and Sterner, 2000).

Raymond and Stern (2000) point out that for the construction client the initial cost can be determined easily and reliably but maintenance and operational costs are less predictable as they extend in the future. For that reason, initial cost is used as the main base for decision making today.

## 3. RESEARCH PROJECT

### 3.1 Project description and objectives

This project is part of the research project InPro (Information and Processes) which links the name to the main focus of the research work. The InPro research project includes 20 European partners representing both industry and research. The idea of the InPro Project is to introduce 3D design and Building Information Models in the European construction sector; moreover, to develop strategies and business models for new building design processes which consider the building's whole life cycle. The main idea is to improve the involvement of the end-user in the early design phase to have more satisfied customers in the construction sector.

This research project aims to explore and indicate the different parameters which are needed to optimise LCC for buildings and to provide the construction client with a better tool for decision in the early design/planning process. The objective of this research project is to provide the construction client with a more holistic picture of the lifetime cost for the planned building, specifically:

- to provide a better understanding of the long term consequences of the decisions in the early design phase to the construction client/end-user and to the planning team;
- to investigate the extent to which LCC estimation is used in the construction industry today.
- to examine ways of improving existing models to form better holistic LCC models that can influence planning in the early stage of design.

This paper aims at exploring the different data that are needed to analyse life cycle costs for buildings. The first objective aims at a structural overview of existing theoretical economic methods for LCC analyses and their advantages and

disadvantages. The second objective is to point out the main data which are required to carry out a LCC analysis. The last objective is to move away from the limited application of LCC to a position where LCC can properly inform the early stage of design decision making.

### 3.2 Research methodology

The literature review started with the focus on life cycle cost models and required data for an LCC analysis. The key words have been life cycle cost (LCC) and life cycle costing. The field of life cycle cost is wide and to be able to keep focus on the construction sector all words have been combined with construction or building. This has narrowed the field. While reading the first literature it came clear that often terms like whole life cost (WLC) and whole life costing been used in the literature, even whole life appraisal (WLA). These words been added to the list of key words. The main sources for the literature research were databases, such as Environmental sciences, Emerald, Elsevier Science Direct, Compendix, web of science and Google Scholar. The search for articles was complemented with systematic search within libraries in Sweden through Libris.

## 4. RESEARCH RESULTS

### 4.1 Initial results

Several cost-based LCC calculation methods are available for the construction sector. They all have their different advantages and disadvantages. According to the reviewed literature, the most suitable approach for life cycle cost in the construction industries are the NPV method or, in the case of comparing alternative schemes with different lifetimes, the ECA. The NPV method is mainly used in existing LCC tools today. The user should bear in mind that different methods have been formed for different purposes. For example, in the case of a rough estimate, to distinguish if the investment is profitable, or not, the payback method would be most suitable. Consequently, other measures shown in table 1 can be used if the proper purposes are considered.

The data can be divided into five main groups: occupancy data, physical data, performance data, quality data and cost data. All of them have to be taken into account for a LCC calculation. The importance of the different data depends upon on the stage of planning in which the calculation is undertaken. LCC is a decision making tool to select among alternative projects, design, or building components. Consequently, the LCC data should be presented in a way that enables such a comparison. The cost breakdown structure is in this case an important aspect.

Sources of data are manufacturers, suppliers, contractors and testing specialist's data, historical data and data from modelling techniques. However, all of them have limited use today according to the literature.

The reviewed literature indicates that LCC calculations need to be considered worthwhile for the construction client. Therefore, data access needs to be facilitated and, consequently, less time and money consuming.

## 4.2 Implementation and exploitation

The collection of the data according to the reviewed literature is the main difficulty for calculating the LCC for a building. This process can involve much time and money. To build databases seems to be a good alternative, and would save time and offer easier access to data. The limitations of databases have, however, to be recognised. First, there is the local limitation and, second, there is often a need to normalize the data before adding to the database. Even so, building local databases would be a solution so long as there is regularly updating.

## 5. CONCLUSIONS

The choice of the right calculation method for LCC is easy and obvious if the advantages and disadvantages are appreciated. The calculation of LCC is not difficult and for structuring the main data, which need to be collected, help is available in the form of different standards such as ISO or the Norwegian standard. Nonetheless, data collection causes difficulties. Data need to be predictable if the LCC analysis is to be reliable. Regional databases are seldom available or usable. To collect data by hand, takes much time and money. This is worthwhile if the project is big enough. When historical data are collected and updated over time, their use can become more reliable and the LCC analysis more trustworthy.

Data should be shared to avoid the duplicated effort of collecting them. If more clients demand LCC information and a proper check of the information against performance is done in the future, improvement in accuracy and reliability could be expected. When LCC is used more frequently, the construction client could judge LCC in the same manner as they do with estimated capital costs today. The construction client, and the end-user, could save much money in the long run, if LCC is adopted as a decision making tool. The lifetime quality and the cost effectiveness of buildings would improve by using LCC in the early stage design.

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