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ScienceDirect
Procedia Engineering 85 (2014) 454 – 463
Procedia Engineering
www.elsevier.com/locate/procedia

Creative Construction Conference 2014, CC2014

Life Cycle Cost optimization within decision making on alternative designs of public buildings

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Abstract

The purpose of this paper is to highlight the role of the life cycle cost criterion in deciding on the proposals of construction projects. Owners commonly use construction cost minimization. In order to achieve the maximum value for money all costs incurred over the whole life span must be evaluated. The optimization of the life-cycle cost of a project, construction, and equipment is essential for a complex decision-making process. Then, the solution with the minimum value of the life-cycle cost can be chosen. Life cycle costing (LCC) is a method of economic analyzing of all costs related to constructing, operating, and maintaining a construction project over a defined period of time. Having the costs and savings we can then directly compared these areas and be fully informed when decisions are made. Nevertheless, LCC is not commonly applied to construction projects in Europe or USA. The greatest benefit of life cycle costing can be obtained in the initiation phase of construction projects. The paper summarizes the issues of life cycle costing (LCC) and analyzing. The paper presents the most frequently used methods of cost calculating. The paper also clarifies the necessary data and a suitable process of life cycle costing is proposed. The paper presents the results of a survey focused on the use of LCC by public owners and developers. Decision-making using the LCC optimization is demonstrated in the case study. This case study is a public building. The client's benefits of integrating LCC into decision-making processes within project preparation are summarized in the conclusion.

Peer-review under responsibility of the Diamond Congress Kft.

Keywords: Building; cost; design; decision; life cycle.

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Peer-review under responsibility of the Diamond Congress Kft.
doi:10.1016/j.proeng.2014.10.572

1. Introduction

The lowest investment cost (the lowest price) is often the only priority in the process of preparation of the budget in a construction project. If we consider a building's lifespan as tens of years, assessing project alternatives in terms of only investment costs occurs as shortsighted and insufficient. Running costs (operation costs, maintenance and renovation costs) are an important section of investment during the life cycle. Life cycle costing (LCC) should be an inseparable part of decision making on financially expensive investments, which most construction projects can be classified. Calculation of life cycle costs provides a completely new economic view on building design. This paper covers the implementation and incorporation of the LCC criterion in the decision making cycle for preparation of construction projects.

RICS (Royal Institution of Chartered Surveyors) introduced a method of collecting data about running costs of buildings in 1971 (BMCIS - Building Maintenance Cost Information Service). The British ministry of industry published a document "Life-cycle costing in the management of assets" in 1977. In 1983, a framework for data collection was published applicable to establishing a project LCC by Flanagan, Norman [1]. The concept of LCC has been accepted as a British Standard since 1992. The LCC definition was revised in 2000 and incorporated in the ISO 15686 Part 1 - Service Life Planning. Recently, a Center for Whole Life Performance has been established at the Building Research Establishment (BRE) to provide the Secretariat to an industry-led Whole Life Costs Forum (WLCF) [2]. This Forum is intended to enable members to pool and receive typical WLC information through a members-only database, and produce industry-accepted definitions, tools, and methodologies. The TG4 group [3] was established as a part of the work group for sustainable construction in 2001. This was done to prepare a report on calculation of LCC in construction and formulate a recommendation how the LCC should be implemented in the European policy. The output is a report "Task Group 4: Life cycle costs in construction". The latest initiative is the project of Davis Langdon [4] "A common European methodology for Life Cycle Costing".

According to [5], life cycle costing (LCC) is a technique to estimate the total cost of ownership. The technique can assist decision-making for building investment projects. LCC is particularly useful for estimating the total cost in the early stage of a project [6]. A LCC process usually includes the following steps: planning of LCC analysis (e.g. definition of objectives), selection and development of the LCC model (e.g. cost breakdown structure, identifying data sources and contingencies), application of LCC model, and documentation and review of LCC results [7]. There have been extensive research and reports on LCC [4]. Nevertheless, LCC is not commonly applied in Europe or USA. There are only some studies relating initial investment to long-term cost [8]. According to ISO/DIS 15686-5 (2006), Life Cycle Costing is both a tool and technique, which enables comparative cost assessments to be made over a specified period of time, taking into account all relevant economics factors both in terms of initial capital cost, future operational costs and asset replacement costs, through to end of its life, or end of interest in the asset. Also LCC will take into account any other non-construction costs and income. Life Cycle Cost (LCC) represents the overall costs spent in course of the building's whole life cycle. There is a part of Whole Life Cost (WLC).

2. Application of LCC in the context of a building's life cycle

Each building passes through several phases during its life cycle. Four basic phases of a life cycle may be defined: Pre-investment phase (preconstruction), Investment phase (construction), Operation phase, and End-of-life phase (liquidation, conversion, modernization, etc.).

Opportunity studies, Pre-feasibility studies, Feasibility studies, and Urbanistic/Architectural studies are developed in the course of the pre-investment phase. Also market analyses and cost-benefit analyses are completed. It is recommended to include preliminary calculations and LCC analyses as well as Life Cycle Analysis (LCA) and Risk Analysis during this phase.

The investment phase consists of preparation and execution of the investment plan (construction). This phase includes the design phase (planning and design) and the construction phase (preliminaries, construction and commissioning). It is advisable to include the calculation and analysis of the life cycle costs in this phase based on the planning documentation, and updates as more detail documents are developed. Included in update are documents for building permission, and also Life Cycle Analysis (LCA) and Risk Analysis. Project documents should be developed specifically based on owner's requirements up to the LCC level, i.e. not only construction costs should be reviewed, but of all those costs generated in course of the operation of buildings. Operations costs (costs of heating and cooling, lighting, cold and hot water supply, sanitation, etc. in buildings), maintenance and renovation costs will establish information for the facility operator. The LCC analysis can be applied when selecting design alternatives, selecting alternative structures (e.g. building envelope, roofing, windows) and selecting services and technologies (e.g. heat sources and heating systems, air-conditioning, security systems, and similar). Contractors have nowadays been motivated to provide the lowest prices possible irrespective of future costs of use. The long-term economic effectiveness should be more emphasized in order to reduce future maintenance and other costs. Those structures, whose failure results in abnormal recovery costs, must be subjected to a detail analysis. Possible design variations must be assessed in terms of their effect on the future LCC. Any such variation of material, different structural design or different technical equipment must be subjected to LCC calculation. If a design variation should worsen building parameters in this respect it should not be permitted.

Maintenance management plays an important role in the operation phase in terms of overall LCC. The criterion for replacement of a structure or equipment is the comparison of increasing operation costs and replacement costs versa related lower operations costs. In this phase it is appropriate to update the calculation of LCC and compare the actual values (i.e. spent costs of power, water, services, cleaning, and similar) with those planned costs. Possible differences may be used for the facility management, but they may also be used as a feedback for similar construction projects.

The last phase of the whole life cycle is the phase of liquidation. Building materials must be stored or reclaimed, and the site must be re-cultivated or prepared for the following project. This ends not only the last phase, but also the whole life cycle of a building.

3. Life Cycle Costing

As discussed in this paper, LCC are overall costs spent during the whole life cycle. These are the costs spent during all four life cycle phases. The greatest benefits from LCC are obtained when they are analyzed in the pre-investment phase. The potential for affecting the overall LCC is at its peak during the pre-investment stage.

3.1. The Structure of Life Cycle Cost in Czech Republic

In most buildings, operation costs take up the greatest share of LCC. This is because these costs relate to the longest phase of the life cycle – use period. Aside from operation costs, a great part of LCC is maintenance and renovation costs. They make up the costs that must be spent to maintain a building in operable condition and prevent and/or remove defects and equipment malfunctions occurring during the life cycle. Each structural element and piece of equipment has a certain expected life span. After that life span has expirated these elements lose their technical capacity, reliability and quality due to natural ageing and use. It takes also money to maintain and renovate them continuously. Depending on the type of a structural element and piece of equipment, costs may have to be spent just once or in cycles. Regular maintenance of a building is very important and should not be neglected. Costs that have to be spent on eliminating various emergencies caused by neglected maintenance are usually much higher than costs of regular maintenance. For possible breakdown of LCC – see Table 1.

Table 1. Life Cycle Cost of Building (LCC).

Group of costs	Cost item
Investment (acquisition) costs	Design and other fees, Construction costs, Cost of operation units, Land, Secondary costs related to locating the building, Other costs, Costs related to machines, equipment, inventory, Other investment costs, Running costs for preliminaries and construction
Operation Costs	Maintenance and Renovation costs, Power supply costs, Water and wastewater costs, Waste disposal costs, Service fees, insurance, Security costs, Cleaning and maintenance costs, costs of maintenance of green, Administrative fees
End of Life Cost	Liquidation costs, Cost of recovery of rubble, Landscaping costs

3.2. Life Cycle Costing Methods

Life Cycle Costing Methods uses costs spent at present and those to be spent in the future. To secure these values as comparable, the time value of money must be considered in calculations. Calculation of LCC works with prognoses of life cycles lengths, future costs, and the discount and inflation rates. When there are not available good data, "treating" this information and data is the key factor for successful implementation of life cycle costing. The most suitable and most commonly used approach to assessing LCC of buildings is the Net Present Value (NVP) and the Equivalent Annual Cost (EAC). The latter mentioned approach is beneficial namely in the case of alternatives with variable life spans.

The standard approach to deciding the alternative in terms of LCC is the selection of an alternative with the lowest net present value of costs. LCC are calculated as the present value of cumulated future annual costs throughout the analyzed period of time [3].

$$NPV = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} \tag{1}$$

NPV … is the present value of LCC,
C_t … sum of all relevant costs after deducting yields generated during the period t,
r … is the discount rate,
t … is the analysed time (t=0…T) (years),
T … is the life cycle.

The Equivalent Annual Cost is used to convert the entire costs of the alternative assumed [to be spent] throughout the life span into the costs spent during 1 year. This is the net present value of the LCC alternative divided by the factor of the present value of constant instalments. Assessing alternatives using the annual equivalent of costs alternatives may be compared featuring a different life span. The optimal alternative in terms of the total LCC is the one with the minimum value of the annual equivalent of cost EAC.

$$EAC_i = \frac{NPV_i}{f_{ta\,i}} \tag{2}$$

EAC_i … is annual equivalent of LCC per alternative i,
NPV_i … is net present value of LCC per alternative i,
f_{tai} … is factor for convergence of annual sums.

3.3. Data for calculation and analysis of LCC

Data necessary for calculation and analysis of LCC may be classified in three groups:

- Data for conversion of costs spent in course of the life cycle to the present value, the so-called discount rate, inflation rate, length of the analyzed period,
- Data on costs, i.e. costs within the defined structure, life cycle phases,
- Other data, i.e. the quality of the building and structures, intensity and method of use, and technical parameters.

In the case of a LCC analysis, the life span of the building and/or its structures and equipment is distinguished from the length of the analyzed period. Buildings are specific by their long technical life usually exceeding the moral or economic life. Most sources agree that for analyzing LCC for buildings, considering a long period is not appropriate. Sources [7] and [9] agree on the length of the analyzed time as a maximum 25 – 30 years. This length might be suitable for public buildings, but the author is of the opinion that private investors should use shorter period, maximum 10 – 12 years.

Investment costs (construction costs) include design and preliminary engineering support, surveying costs, costs for technology units, auxiliary costs related to siteing of the project, costs of operational units, costs of machinery, technology and inventory and costs for preliminaries and construction. These costs are easy to estimate in the preliminary design phases; there are many reference documents that can be used for this. Historic data may be used to estimate the maintenance costs. Databases of maintenance and renovation costs exist abroad, for example BMI [10]. Each project is different and this is why a professional opinion plays an important role in estimating maintenance and renovation costs. To estimate modernization or renovation costs a comparison with similar projects may be used provided this is used for estimation of the cycle duration and costs. Operation costs for buildings consist of costs for power, cleaning, insurance and facility management, and other similar costs. Power costs depend on the intensity of use, type of building operation, climatic conditions, users´ requirements on services and building environment, and naturally on the design and thermal technical parameters (Bordass, [11]). This is the reason it is important to select a comparable building when searching data for the estimation. Sharma et al. [12] have developed construction and operation cost models from historical cost data. This model can be used to develop preliminary cost estimates and to screen alternative process during the planning phases of the project.

Physical aspects of buildings are measurable. These are floors, walls, windows and door areas, and a number of other items. The size of a building, number of stories, layout, and design affect the value of operation costs. Another important factor is the time of operations and profile of users, particularly for public buildings.

3.4. Approaches to calculation of LCC

A deterministic approach is based on the assumption that each entry value for calculation of LCC is a fix, discrete value. This calculation uses values that are the most likely to turn up based on historical evidence and professional assessment. Deterministic calculation of LLC is easy in terms of computation, yet it involves certain equivocation related to estimation of present values. Defining the cost profile of alternatives may be sophisticated, combining optimisation methods and life cycle prognosis. This method consists of developing a cost profile of the analysed alternatives (a series of cost estimates for preliminaries, construction, maintenance, operation and liquidation throughout the life cycle). The Net Present Value is then calculated for the cost profile (Formula 1) or the Equivalent Annual Cost (Formula 2). Based on the results, alternatives are ranked and the best one is recommended for realization. The deterministic approach to calculating LCC must be complemented by a sensibility analysis. The Net Present Value (NPV) or Equivalent Annual Cost (EAC) of Life Cycle Cost of the cheapest alternative is the dependent variable in calculations of LCC and the entry parameter is an indeterminate quantity. Sensitivity of the NPV or EAC of the alternative's life cycle throughout the analysed time, discount rate, and similar is researched.

According to Kishk et al. [13], the goal is to find a break-even point defined as the entry parameter value causing the cheapest alternative's LCC to become equal to the second cheapest one.

A stochastic approach does not use the entry calculation data as discrete values, but random variables with assigned probability density functions. This approach builds on randomly dividing individual LCC items, the discount rate, and time according to one of the theoretical distribution functions [114].

$$f(LCC) = f(C_P) + \sum_{t=0}^{LC} \frac{f(C_{ti})}{(1 + f(r))^t} \tag{3}$$

f(LCC) … is the distribution function of probability of LCC at its present value,
f(Cp) … is the distribution function of probability of acquisition costs,
f(r) … is the distribution function of probability of a discount rate (time value of money),
f(Cti) … is the distribution function of probability of each item of relevant costs throughout the life cycle (LC) of property after deducting positive the cash flow, e.g. the residual value of the building or the value of the land for sale,
LC … is the length of the building's life cycle.

Obtaining probability data for variables model may be difficult. The alternative is selected based on the risk preference rate.

4. Implementation of LCC in decision making

Procurement is a key process in a construction project. Construction procurement is a complex process with a large number of available options. Modern initiatives such as sustainability, life-cycle costing, and standardization are getting integrated with procurement. Ruparathna and Hewage [15] present a comprehensive review of traditional and emerging procurement practices in the construction industry. Contemporary developments in construction procurement are investigated.

The LCC calculation should be used as a tool for effective selection from project alternatives in every phase of the project's life cycle. The potential of its effective use is in the design phase. The possibility to affect the LCC decreases with the project development from 100 per cent to approximately 20 per cent in the construction phase. Only a very small chance to affect operation costs exists at the moment construction commences. Literature refers that 80 to 90 per cent of operation, maintenance and renovation costs are determined just by the design. Implementing the LCC criterion in the decision making during the design will allow a more effective selection among competitive alternatives (design, detail, structure, equipment).

The value of the LCC criterion is set up based on LCC calculation. Depending on where in the construction phase, LCC may be a preliminary calculation or a detail calculation of LCC in the later investment phase (design phase). The detail LCC calculation is based on more specific project documents and data. Parallel with the detail LCC calculation of the building as a whole are conducted detail calculations regarding structures, equipment, materials, and other crucial items in terms of costs. For the decision-making process – see also Table 2.

Table 2. Decision-making process based on LCC criterion.

Number of the activity	Activity
1	Defining the purpose and scope of decision making
2	Defining of the range and key parameters for LCC calculation
3	Summarizing data to the evaluated alternatives
4	Economic evaluation of alternatives
5	Selection of the optimum alternative based on the LCC criterion

Total LCC are calculated in the frame of the economic evaluation. For example either as the Net Present Value or the Equivalent Annual Cost. Also LCC may be calculated using the internal yield rate or recovery rate. The obtained costs may be presented as: LCC (at present prices of NPV), LCC per 1m2 usable floor area, per 1 functional unit (m^2 of offices, 1 student), building's annual equivalent LCC or LCC for key structures and equipment, i.e. EUR/year, LCC per 1m^2 of usable floor area per year (EUR/m^2.year), cost per a functional element, component, or system.

5. Case study

Buildings in the Czech Republic account for 53% of the national annual energy consumption, 45% of carbon footprint, and 20% of water consumption. To minimize these negative environmental impacts and improve life-cycle cost performance, a slowly increasing number of public and private owners are requiring that their existing and new buildings incorporate more sustainable building measures. Compare with [16].

The example project is the design of the Central Depository of the Museum of Decorative Arts in Prague (MDAP). This is a building with two underground and three aboveground stories, compact in shape, with a circular footprint of a regular equilateral polygon with 120 sides. The loadbearing structure is a reinforced concrete cast in-situ frame combined with reinforced concrete walls. The built-up volume is 60,000 m^3; the built-up area is 2,800 m^2. It is a project with public funding. The Table 3 below shows the decision making process based on the LCC criterion.

Table 3. Decision making process.

Step	Contents
1. Determining the decision making goal	Support/refusal to build the Central Depository of the UPM according to the low-energy standard (Alternative 2), comparison with the current condition (Alternative 1)
2. Defining the range and key parameters of the LCC parameters	Project phase: before starting designing the documentation for building permission, i.e. preliminary calculation of LCC
	Relevant costs:
	construction costs – buildings, project and engineering support services, surveys, land
	operating costs – power, water and sewerage fees, cleaning, facility management and admin., insurance
	Discount rate: 3% (alt. 0% and 6%)
	Analyzed period: 30 years (alt. 50)
	Low-energy standard: walls = 0.13 W/m2K, roof = 0.11 W/m2K
	Cooling of the Central Depository with (de)humiliation to year-round 50 % ± 5 %
3. Summarizing the data referring to	Alternative 1 (current): in-house data, accounting (operator)

the evaluated alternatives	Alternative 2: expert estimates (designer, technical institution)
4. Economic evaluation of alternatives	Calculation of LCC (NPV)
	Risk assessment, precariousness
	Sensitivity analysis (effect of a change of a discount rate, length of time)
5. Selection of the optimum alternative based on the LCC criterion	Comparison of LCC for Alternative 1 and 2
	Comparison of running costs for Alternative 1 and 2
	Recommendation to build a low-energy building

Table 4 presents the review of LCC calculation for the design of the Central Depository of the MDAP [17]. The calculations were conducted for two alternative periods: 30 and 50 years. Construction and operating costs are estimated based on the developed documents used for planning permission. Land related cost is the purchase price; the price of the project documents and engineering support services are the result of a public request for proposal; the price of surveys is taken over from the books. Buildpass [18] software was used to estimate the costs of renovation (set up using the ratio model for a comparable public amenity). Aside from the total LCC for a building the cost per 1 square meter of usable area is also presented. The liquidation costs are not subject of this analysis. The impact on the LCC of discount rates and period of analysis was tested.

Table 4. LCC of Alternative 2 (design of new build), period of analysis = 30 year, discount rate 3%, basis of cost 2013

Cost Category	Total (EUR)	Unit cost (EUR/m2)	Total (EUR) - NPV	Unit cost (EUR/m2)
Building	13 461 538	1 303	13 461 538	1 303
Design and other fees	523 077	51	523 077	51
Land	1 153 846	112	1 153 846	112
Construction costs and land - total	15 138 462	1 465	15 138 462	1 465
Maintenance costs	6 014 865	582	3 906 140	378
Operation costs	4 913 538	476	3 210 251	311
Disposal costs (excluded)	0	0	0	0
Total Life Cycle Cost	26 066 865	2 523	22 254 852	2 154

Table 5. Comparison of (EUR/m2) Alternative 1 and 2, discount 0%, period of 30 years.

LCC item	Alternative 1 (current state)	Alternative 2 (new build)
Maintenance costs annualised (EUR/m2year)	4,31	7,46
Operation costs annualised (EUR/m2year)	62,31	15,85
Total = maintenance + operation, annualised (EUR/m2year)	82,46	23,31
Maintenance costs per analysed period (EUR/m2)	129,23	223,85
Operation costs per analysed period (EUR/m2)	1 869,23	475,38
Total running and maintenance costs per analyse period (EUR/m2)	1 998,46	699,23

The decision to carry out the investment, the Central Depository of the Museum of Decorative Arts in Prague (MDAP) is supported as correct. Running costs related to 1 m^2 of usable area are substantially lower in the case of the Central Depository compared with the reference alternative; they establish only 25 % of running costs of the Alternative 1 (current state).

6. Summary and Conclusion

A questionnaire was sent to members of Association for Public Works. Questions concerned information about calculating and analyzing life cycle costs. Results of this questionnaire research show that though both commissioners, and advisors attribute importance to life cycle costing (86 %), they generally do not consider LCC in actual commissions (76 %). They have none (23 %) or only superficial (56 %) knowledge of the problematic. If there were clear methodic for LCC, they would apply it to commissions (76 %). Most respondents (81 %) stated that LCC is a good evaluation criterion at least partially in certain cases of public commissions. There is a big gap in the application of LCC in public procurement.

Decision making based on the LCC criterion brings benefits to the owner. The following items are among the benefits: transparency of future operating costs, better awareness of total costs, ability to affect and optimize the future costs in the design phase, harmonizing with public requirements on construction (principle 3E), evaluation of mutually replaceable design alternatives or their parts, evaluation of a solution compromising between project technical parameters and costs (substitution of materials., technologies, etc.). Gharaibeh [19] concludes specific practices and a set of recommendations that should be implemented by project teams to help in managing the cost of projects.

In order to achieve the above-specified benefits, the following must be ensured:

- teamwork of all key persons, the owner (client), the architect, technical supervisor(s), professional consultants and others;
- integration of LCC calculations into the overall investment decision making process – development of the concept, design work, construction, and operation;
- sufficient entry data. Output from LCC calculations is highly dependent on the level of detail and accuracy of data (particularly costs, time).

The LCC analysis was used for a public building, the Central Depository of the MDAP. Based on data obtained from the engineering office and the project documents for planning permission, a preliminary calculation was conducted for the purpose of strategic decision making. This analysis concluded that the decision to build the Central Depository in the proposed low energy standard was the best. Making decisions based on the LCC criterion represents a completely new economic view of construction projects in the design phase. Assessing of buildings (investment projects) in terms of life cycle costs is one good possibility to meet criteria 3E, i.e. their economy, effectiveness, and efficiency. This is important for projects financed from public funds that must clearly demonstrate financial effectiveness.

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