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LIFE CYCLE COSTING IN THE PREPARATION OF PUBLIC WORKS CONTRACTS

Renata Schneiderova Heralova[1]*

[1] Czech Technical University in Prague, Faculty of Civil Engineering, Thakurova 6/2077, 166 29 Praha 6, Czech Republic

Abstract

The purpose of the paper is to highlight the role of life cycle cost as a criterion in preparation of public works contracts. Contracting authorities commonly use construction cost minimization as an important criterion. In order to achieve the maximum value for money and 3Es, all costs incurred over the whole life cycle must be evaluated. The optimization of life-cycle cost of a project, construction, and equipment is essential for complex decision-making process. Life cycle costing (LCC) is a method of economic analysis of all costs related to construction, operation, and maintenance of a construction project over a defined period of time. All costs and savings can then be directly compared and fully informed decisions can be made. The greatest benefit of life cycle costing can be obtained in the initiation phase of construction projects, it means even before the call for tenders. The paper summarizes major issues of life cycle costing (LCC) and analysing, and presents the most frequently used methods of cost calculating. The paper also clarifies necessary data; a suitable process of life cycle costing is proposed. The paper presents the results of a survey focused on LCC usage by public investors and developers. Most respondents (81 %) stated that LCC is a good evaluation criterion at least partially in certain cases of public tenders. Assessing buildings (investment projects) in terms of life cycle costs makes it possible to meet the criteria of 3Es, i.e. their economy, effectiveness, and efficiency. This is important for projects financed from public funds that must clearly demonstrate financial effectiveness.

Key words

Decision-making; life cycle cost; public works; tender

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*Corresponding author: Tel.: +420-224-354-522, Fax: +420-224-355-439
E-mail address: heralova@fsv.cvut.cz

1 INTRODUCTION

Public works contracting is a problematic issue. Unfortunately, it is still common that the low price wins over quality matters or in the worst case, both low quality and high price. The aim is to ensure optimal management of public expenditure.

European directives and guidelines, together with national legislation, provide obligations for the contracting authority relating to economic issues, evaluation, and check-ups on public contracts. Key concepts are defined as so-called principles of 3Es (i.e. following the criteria of economy, efficiency, and effectiveness). Each contract for construction work is unique; the course of building itself always adheres to individual demands of the customer. These requirements are expressed in the design documents, delivery and quality terms. A public works contract is usually preceded by public contract for services, i.e. project documents, engineering, or technical supervision on behalf of the investor. Design documents should also follow the aforementioned criteria of 3Es. The resulting technical parameters of a building are influenced by quality of project execution, materials used, or equipment. Relating operating costs may thus often be only confirmed in operating phase of a given project. To provide the criteria of economy, efficiency, and effectiveness in a project, the whole life-cycle of such project needs to be taken in account as early as the designing phase (values need to be calculated to count whole life costing/ life cycle costing).

According to ISO/DIS 15686-5 (2006), Life Cycle Costing is both a tool and a technique, which enables comparative cost assessments to be made over a specified period of time, taking into account all relevant economic factors both in terms of initial capital cost, future operating costs and asset replacement costs, until the end of its life cycle, or end of interest in the asset. Also, LCC will take into account any other non-construction costs and income related to the project. Life Cycle Cost (LCC) represents the overall costs spent during the course of a building's whole life cycle.

When commissioning a construction project financed by public funds, the contracting authority rarely takes operating costs into account. Thus the contracting authority does not consider whether there would be enough money to finance project operation, refurbishment or maintenance costs. However, acquisition costs are mostly the sole priority (i.e. lowest bid price for public contract). It is insufficient and short-sighted to evaluate buildings merely by the criterion of acquisition price, as the expenses of operating phase form a substantial part of overall costs of a project (operating costs, maintenance and refurbishment costs). Life cycle cost calculation is a straightforward idea, saying that all relevant costs need to be taken into account during the process of decision-making. Life cycle cost calculation combines managerial, financial, and technical skills and stretches these over all phases of a project life cycle.

Life cycle cost calculation may be used as both absolute and comparative analysis. Absolute analysis is useful as a form of support of designing, planning, creating a budget, and making construction contracts. Comparative analysis serves to choose out of several options, e.g. modes of acquisition, construction design, or different technology options. The investor should demand that designers create project design, details, etc. in several variations, so that optimization of life cycle costs can be performed. The inclusion of life cycle costs in decision-making allows efficient choice among competing alternatives in a project (design, details, structures, equipment) because capital costs, maintenance, refurbishing, and operating costs are all taken into account, and expressed by means of consistent and comparable quantities.

The purpose of the paper is to highlight the role of the life cycle cost criterion in preparation of public works contracts. Contracting authorities commonly use construction cost minimization as both a criterion, and a goal. In order to achieve the maximum value for money and 3Es, 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.

2 LITERATURE REVIEW

The issues of life cycle costing, and its analysis has been of interest around the world for a long time now. In 1980s, demands were made concerning creation of uniform methodology for evaluation of life cycle costs, their analysis, and optimization. Various methods and standards have been created since, usually on national levels, or with specific concern to an area of construction business. Most documents (with only slight diversions) divide project life cycle into investment phase, operating phase, maintenance phase, and the end of life cycle. Costs are divided into similar categories, and similar methods are used to evaluate the optimal alternative, especially discounting all future costs towards net present value. However, it is not stated anywhere how to find out or calculate the individual costs. Information is mostly linked to local databases, historic or statistic data. Assignation of such documents also varies a lot – with regard to educational buildings, rental buildings, public sector, etc.

Theoretical grounds for calculating life cycle cost have been described for over 20 years in foreign literature [1] [2] but it is hardly ever applied in practice of construction projects. The general procedure of life cycle cost calculation consists of 4 steps:

- definition and description of options to be evaluated,
- identification of relevant economic criteria,
- obtaining and alignment of relevant costs,
- risk assessment.

RICS (Royal Institution of Chartered Surveyors) introduced a method of collecting data about operating costs of buildings in 1971 (BMCIS - Building Maintenance Cost Information Service). The British ministry of industry published a document called “Life-cycle costing in the management of assets” in 1977. In 1983, Flanagan and Norman published in [3] a framework for data collection, which is applicable to establishing project life cycle costs (The concept of LCC has been accepted as a British Standard since 1992). The definition of LCC was revised in 2000 and incorporated in the ISO 15686 Part 1 - Service Life Planning.

In 1995, Sieglinde K. Fuller [4] and Stephen R. Petersen [5] wrote a handbook called Life-cycle Costing Manual for the Federal Energy Management Program for the National Institute for Standards and Technologies (NITS). The handbook was presented to the Ministry of Energetics of the United States of America to evaluate potential savings of power, water, and renewable energy sources in all federal buildings from an economical viewpoint. This set the groundwork for LCC analysis.

Recently, a centre for Whole Life Performance was established at the Building Research Establishment (BRE) to provide the Secretariat to an industry-led Whole Life Costs Forum (WLCF) (in [6]). This Forum is intended to enable members to pool and receive typical WLC information through a members-only database, and produce industry-acceptable definitions, tools, and methodologies (Edwards et al in [7]). TG4 group was established as a part of work group for sustainable construction in 2001. The group was set up to prepare a report on calculation of LCC in construction and formulate a recommendation how LCC should be implemented in the European policy. The output is constituted by a report called “Task Group

4: Life cycle costs in construction". Their latest initiative is a project called "A common European methodology for Life Cycle Costing" (Davis Langdon in [8]).

According to [9], Life cycle costing (LCC) is a technique to estimate the total cost of ownership. Flanagan et al in [10] summarize that the technique can assist decision-making for building investment projects. Bogenstatter in [11] emphasises that LCC is particularly useful for estimating total cost in the early stages of a project. LCC process usually includes the following steps: planning of LCC analysis (e.g. definition of objectives), selection and development of an appropriate LCC model (e.g. cost breakdown structure, identifying data sources and contingencies), application of LCC model, and review of LCC results with its ensuing documentation [12]. There has been extensive research and many reports on LCC (in [8]).

In the Czech Republic, life cycle cost analysis is predominantly carried out by universities. Several research projects have been started. The most notable of these are the following:

- Management of sustainable development of life cycle of construction projects, construction companies, and areas (CTU Prague, 2005 – 2011). Research focused mainly on elevating the benefits of investments (buildings, constructions, commercial investment products) for regional economics and public users with concern of specific techno-economic tasks (in [13]).
- CIDEAS – Centre for Integrated Design of Advanced Structures (CTU Prague, 2005 – 2009). The aim was to create a model which would allow to calculate dynamics of costs during whole life cycle of a construction project. The system is based on deterministic algorithm with a reference database of building objects and structural elements. While solving the goal task, methods of calculating life cycle costs of construction objects were devised as source material for applicable model which could be used for various types of construction objects [14].
- Optimization of technical-economic characteristics of construction project life cycle (TU Brno, 2004 - 2008).
- Advanced construction materials using secondary raw material, and their impact on structure durability, Economic aspects of using new construction substances with waste material (TU Brno, 2005 - 2010). The outcome of this research is an application focusing on substitution of specific construction materials, and its impact on overall life cycle costs of a building. It allows comparison of different material options, and simplifies selection of the optimal material. Life cycle costing is performed by means of calculation and its comparison to a pre-defined building of the user's choice. The database includes a set of case studies of selected buildings. [15, 16, 17]

Nevertheless, LCC is not commonly applied to construction projects in Europe or USA.

3 METHODOLOGY

As discussed in this paper, LCC are overall costs spent during the whole life cycle of a project. The greatest benefits are obtained from LCC when data are analysed in the pre-investment phase. The potential for affecting overall LCC is at its peak during the pre-investment stage.

3.1 The process of life cycle cost analysis

Preliminary LCC analysis in the pre-investment phase is usually followed by a detailed LCC analysis during the investment phase (in the stage of design creation). Together with a detailed

LCC analysis of the project as whole, detailed analyses are created for key structures, equipment, material, etc. from the viewpoint of investments. The typical course of action is:

1. LCC model of the project in pre-investment phase,

2. Detailed LCC model of the project in investment phase (based on detailed information from project design),

3. LCC calculation for selected key systems/components, and their various options (part of project value management) – e.g. air conditioning system, siding, components such as fan, pump, roofing, surface finish,

4. Integration of system/components options from the previous step into project design, and a detailed analysis of LCC of the whole project.

Tab. 1: The process of LCC analysis application

1	Setting a goal for LCC analysis
2	Stating the extent of LCC analysis
3	Defining key parameters
4	Defining options for analysis processing
5	Gathering data for options to be evaluated
6	Economic evaluation of options
7	Final report

The process of LCC analysis application is shown in Table 1. LCC analysis starts with a goal setting that is to be reached by means of stated analysis. That may be proceeding towards source material which is to be used in strategic investment decision, creating a plan for future investments, preparation of future operating costs budget, evaluation of long-term sustainability of a designed project or its options, comparison of strategic investment options. Further goal may be evaluation of several options in execution of a project or LCC evaluation of systems or units, comparison of various options of the system/unit from the viewpoint of LCC for a delimited period.

After setting goals it is necessary to set a time plan including eventual milestones; the client is required to clarify the specific reporting requirements. LCC analysis may be linked to following processes, such as value management.

Key parameters for LCC analysis are:

- costs – the extent of costs included in calculation, their structure, manner of expression in numbers, indexing from the viewpoint of a timeline, location, etc.,
- time – delimitation of time-span to be analysed (technical durability of a structure/ equipment, moral or economic durability),
- method of economic evaluation – calculation of net present value (NPV), discounting rate used, inclusion of inflation rate in calculations, delimiting parameters for sensitivity analysis, and risk analysis methods.

Depending upon the phase of building life cycle in which LCC analysis is applied, these options may apply:

- ways of reaching goals, or meeting the client's needs (e.g. extending the capacity of an administrative building when compared to equipping the company for employees with home office),
- ways of possible use for a currently existing building (efficiency of use),
- alternate options of investment,
- different extents of a project (options of flooring extent, number of floors),
- reconstruction of an existing building vs. new project,
- project designs, reconstruction designs,
- options of structures or units – key items which influence LCC greatly (roofing, siding, aperture filling, heating and air-conditioning, heating medium etc.).

LCC needs large amounts of data for its proceedings, mainly:

- option parameters,
- project design, technical report, specifications, schedule, bill of quantities, technical documents from suppliers of equipment, systems, and materials, etc.
- information on purported use,
- maintenance requirements,
- client's requirements for building's functional standards,
- costs related to end of life cycle,
- cleaning requirements, water and energy consumption,
- administrative costs.

Ideally, client's own historic data is used, data from comparable projects, consultants' services, published data – the Internet, suppliers' materials, research, etc. It is always recommended to check data for their origin, predicative properties (i.e. how many objects they take into account), usefulness for current project (similar type of building), and to correct calculations to current price level, and take location into account as well.

Total LCC are calculated in the frame of economic evaluation. For example either as the Net Present Value or the Equivalent Annual Cost. LCC may also 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 1 m^2 of usable floor area, per 1 functional unit (1 m^2 of offices, 1 student),
- Building’s annual equivalent LCC or LCC for key structures and equipment, i.e. EUR/year,
- LCC per 1 m^2 of usable floor area per year (EUR/m^2/year),
- Cost per functional element, component, or system.

Final report usually contains:

- description of building, project, and LCC calculation process as a support tool for investment decision-making,
- tabular and graphic information, i.e. sum of cost, schedule, annual expenses, resume of key parameters of the analysis (time-span, original data, model data, location factor, inflation rate, discounting rate), expenses in real numbers, costs discounted to present value, annual cash flow (annual costs, cumulative costs, nominal costs per year [including inflation], NPV of annual costs, NPV of cumulative costs), detailed LCC model for analysed options, risk assessment report, and sensitivity analysis of key variables.

For possible breakdown of LCC used in the Czech Republic – see Table 2.

Tab. 2: The Structure of Life Cycle Cost in the Czech Republic

Life Cycle Cost of Building (LCC)	
Investment (acquisition) costs	**Operation Costs**
• Design and other fees	• Power supply costs
• Construction costs	• Water and wastewater costs
• Building lot	• Service fees, insurance
• Secondary costs related to locating the building	• Security costs
• Other costs	• Cleaning and maintenance costs, costs of maintenance of greenery
• Costs related to machines, equipment, inventory	• Administrative fees
• Other investment costs	**End of Life Cost**
• Running costs for preliminaries and construction	• Demolition costs
Maintenance costs	• Cost of recovery of rubble
Renovation costs	• Landscaping costs

3.2 Life Cycle Costing Methods

Life Cycle Costing Methods use both present and future costs of a project. To secure these values as comparable, time value of money must be considered in calculations. Calculation of LCC works with prognoses of life cycle lengths, future costs, and discount and inflation rates. When reliable data are not available, successful implementation of life cycle costing depends on how the lack of data is dealt with. The most suitable and most commonly used approach to assessing LCC of buildings is Net Present Value (NVP) and Equivalent Annual Cost (EAC). The latter mentioned approach is beneficial namely in the case of alternatives with variable life spans. Selection of an alternative with the lowest net present value of costs is nowadays the most common approach to deciding among various options in terms of LCC. LCC are calculated as the present value of cumulated future annual costs throughout the analysed period of time (in [18]).

Equivalent Annual Cost is used to convert the entire costs of the chosen option [to be spent] over the course of its life span into costs spent over the course of 1 year. This is calculated as the net present value of the LCC alternative divided by the factor of the present value of permanent instalments. By means of Equivalent Annual Cost, it is possible to compare various options even if their life spans differ. The optimal choice in terms of the total LCC is the one with the minimum value of EAC.

3.3 Approaches to calculation of LCC

A deterministic approach is based on the assumption that each entry value for calculation of LCC is a fixed, discrete value. The calculation uses values that are the most likely to turn up, based on historical evidence and professional assessment. Deterministic calculation of LCC is simple in terms of computation, yet it involves certain equivocation related to estimate of present values. Defining the cost profile of various options may be sophisticated, as it needs a combination of optimization methods and life cycle prognosis.

The method consists of developing a cost profile of the analysed options (a series of cost estimates for preliminaries, construction, maintenance, operation and demolition throughout the life cycle). Net Present Value is then calculated for the cost profile or Equivalent Annual Cost is calculated. Based on the results, options are ranked and the best one is recommended for execution.

Deterministic approach to calculating LCC must be complemented by a sensitivity analysis. Net Present Value (NPV) or Equivalent Annual Cost (EAC) of Life Cycle Cost of the cheapest option is a dependent variable in calculations of LCC and the entry parameter is an indeterminate quantity. Sensitivity of the NPV or EAC of given option's life cycle throughout the analysed time, discount rate, and other parameters is researched. The goal is to find a break-even point defined as the point when the entry of a parameter value causes the cheapest option's LCC to become equal to the second cheapest one (Kishk, Al-Hajj, Pollock, Aouad, Bakis, Sun, in [19]).

A stochastic approach does not use entry calculation data as discrete values, but rather as random variables with assigned probability density functions. This approach builds on randomly dividing individual LCC items, discount rate, and time according to one of the theoretical distribution functions (Boussabaine, Kirkham, in [20]). The final option is selected based on risk preference rate.

3.4 Case study

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 m3; the built-up area is 2,800 m2. It is a project with public funding. Table 3 presents the review of LCC calculation for the design of the Central Depository of the MDAP (Schneiderova Heralova in [21]). 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 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.

Tab. 3: LCC of Alternative 2 (design of new build)

Project Title: Central Depository of UPM **Perios of Analysis:** 30 years			**Discount rate:** 3% **Basis of Cost:** 2013	
Cost Category	**Total (EUR)**	**Unit cost (EUR/m^2)**	**Net present value (NPV)**	
			Total (EUR)	**Unit cost (EUR/m^2)**
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**

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).

4 SURVEY AND RESULTS

A questionnaire was sent to members of Association for Public Works. Questions concerned information about calculating and analysing life cycle costs. The number of respondents was 43. Results of this questionnaire research show that though both clients, 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 methods 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 tenders preparation.

Despite the rather long history of LCC, its general use in practice has certain limits. Among these, let us name motivation to perform LCC, and most of all, access to relevant data. Acquisition costs of a building are easily calculated with regard to a number of source data. However, operation and maintenance costs can only be predicted. Despite the fact that LCC would be beneficial especially in commissioning public works, bureaucracy poses yet another problem – one group of officials administers investments, another group administers operating costs. It is difficult to gather data about operating costs of different types of buildings. Yet, information about structure and equipment durability is available, with the exception of advanced materials and structures, used predominantly in sustainable (low-energy) buildings. With these advanced materials, only predictions and estimates can be made.

5 DISCUSSION

A wide range of data is necessary for processing of life cycle costs analysis in a project. While working on the case study – an analysis of life cycle costs for the Central Depository of the Museum of Decorative Arts – there appeared a major problem of the lack of information on the costs of operation, maintenance, and refurbishing of comparable buildings. Therefore a database needs to be established, which would be publicly accessible and annually updated, and where data would be obligatorily uploaded by public facility operators. Such data would then serve as feedback to confirm predictions of life cycle costs, and also be important sources for LCC analysis in evaluation of project designs. Management of public funds ought to be transparent, economical, effective, and efficient (3E).

The database would sort buildings into categories according to CZ-CC building classification. Data specifying walled space and floor area would inform the users and help them compare buildings from the viewpoint of project extent. Individual units constituting final cost need to be uploaded together with information on price level, i.e. which year's price levels served as sources for the calculation of costs. In a detailed database, operating costs may further be divided into energy, water, and wastewater costs, service fees, insurance, security, maintenance of greenery, administration fees.

6 CONCLUSION

Methods of LCC analysis can easily be used by both private and public sector. Their use in public sector is characterized by certain specific features. These are, above all:

- use of low or zero discount rate when calculating Net Present Value (NPV), which mirrors the specifics of public works projects, where social aspects outweigh the aspect of profit,
- analysis is performed for whole life cycle, or for a long span of time (in private sector, the usual time-span is 20 – 30 years),
- due to low or zero income flow, structure and equipment choices are usually base on the criteria of durability and sustainability (focus on social and environmental impact).

Zero discount rate should be used for all public sector investments which are designed as legacy for generations to come.

LCC analysis was used for a public building, the Central Depository of the Museum of Decorative Arts in Prague. Based on data obtained from the engineering office and 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 proposed low energy standard was the best decision possible.

Decisions based on the LCC criterion represent a completely new economic view of construction projects in the design phase. Assessing buildings (investment projects) in terms of life cycle costs makes it possible to meet the criteria of 3Es, 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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