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METHODOLOGY FOR EVALUATION OF THE LIFE CYCLE OF BUILDINGS WITH A FOCUS ON THE PRIVATE SECTOR

Renáta Schneiderová Heralová*, Eduard Hromada, Jakub Holcman, Stanislav Vitásek

Czech Technical University in Prague, Faculty of Civil Engineering, Department of Construction Management and Economics, Thakurova 7, 166 29 Praha 6, Czech Republic

* corresponding author: heralova@fsv.cvut.cz

Abstract. The paper describes the innovative methodology for the evaluation of the life cycle of buildings, which will be used in construction projects of Skanska, or other construction companies, in selecting the optimal solution from the point of view of construction engineering and LCC. The aim is to help LCC to be perceived by construction practice as a topic that needs to be addressed at the beginning of each construction project. The quantification of life cycle costs based on relevant input data on the technical parameters of the construction, structural elements and equipment, the time period of incurring the related costs should be an important basis for the decision of the investor, designer and future user of the building also with regard to environmental and social aspects, and in particular the long-term economic consequences.

Keywords: Building, life cycle, life cycle costing, methodology.

1. Introduction

This paper deals with innovative methodology in construction company Skanska concerning the evaluation of construction's life cycle costs (LCC). Mentioned methodology will be applied to construction projects of blocks. This will lead to optimal choices accounting for technical aspects of construction, and LCC from the very moment of designing a construction.

According to the International Standard [1], life cycle costing is a valuable technique that is used for predicting and assessing the cost performance of buildings. Life cycle costing is one form of analysis for determining whether a project meets the clients performance requirements. Life cycle costs (LCC) mean involving all of the costs deriving from the use of buildings during their entire life span. The LCC methodology is a tool for evaluating these costs over time. Its main goal is to assess the various designs, where those designs differ not only in their acquisition costs but also in their operational and maintenance costs.

Assessment of life cycle costs is a valuable tool for both the construction company and the eventual user of construction. Both company and end user are clearly informed about total costs from the beginning of construction. Therefore, they do not need to concentrate only on investment costs or use them as the single criterion of choice. Options of construction may be designed as soon as the designing phase of a project. So the end user obtains higher added value and may compare variant designs to reach optimal value for money. Variant designs enable better choices of construction suitable for the end user's requirements. End user may plan eventual maintenance costs accordingly. This advantage may be the key factor especially for end users who finance the construction with third party resources, such as loans. Life cycle planning lowers the amount of risk in the investment. Transparency can be reached as to operational costs of construction. With life cycle costing it will be possible to benchmark competing projects. LCC analysis has already been implemented as one of the measures for varied certifications, which serve for project evaluation (BREEAM, LEED, SB Tool, etc.).

2. Literature overview

Buildings and constructions are long-term possessions. This is the reason why all decisions connected with a construction project have long-term and significant impact [2]. Construction project investors have often focused only on the acquisition costs, when they were about to make decisions on such matters as the building design, facilities, fittings. They often neglected future operation and maintenance costs [3].

Life cycle costing is a method assisting an effort to estimate the total cost of ownership. The method is able to help in making decisions within building investment projects [4]. Life cycle costing is particularly useful for estimating total costs at the early stage of a project [5]. Life cycle costing consists of all costs directly connected to a construction during its whole existence. That is building costs, maintenance and renovation of construction units' costs, facility equipment costs, facility management and operation costs, demolition costs. [6] Many authors also link other factors closely with life cycle costing. Among such factors, let us name externalities, non-construction costs and income which arise from

ID	Category	Designation	Description
1	Const.	**MCW**[1]	**WORKS AND PROVISIONS**
2	Const.	1	Ground works
3	Const.	2	Ground solidification
4	Const.	3	Vertical and complete constructions
5	Const.	4	Horizontal constructions
6	Const.	6	Finishes and flooring
7	Const.	60	Finishes internal
8	Const.	63	Flooring and floor construction
9	Const.	9	Other constructions and works, demolition
10	Const.	90	Other constructions and works
11	Const.	94	Scaffolding, construction lifts
12	Const.	96	Demolition of constructions
13	**Const.**	**ACW**[2]	**WORKS AND PROVISIONS**
14	Const.	71	Insulation
15	Const.	711	Water, moisture and gas insulation
16	Const.	76	Constructions
17	Const.	763	Assembled constructions
18	Const.	764	External plumbing
19	Const.	766	Carpentry
20	Const.	767	Ironworks
21	Const.	768	Panel work - windows
22	Const.	77	Flooring
23	Const.	771	Floors - tiled
24	Const.	775	Floors - wooden, frieze, floating
25	Const.	776	Floors - thin finish
26	Const.	777	Floors - cast, synthetic
27	Const.	778	Floors - double
28	Const.	78	Finishing works
29	Const.	781	Ceramic tiles
30	Const.	784	Paintwork and wallpapers
31	Const.	788	Fire-fighting devices
32	Const.	789	Facade casing and contact insulation
33	Const.	790	Roof constructions
34	Const.	791	Roof vegetational
35	Const.	792	Roof trafficable
36	Const.	793	Roof non-trafficable
37	Const.	794	Roof movable
38	**Monolith**	**MCW**[1]	**WORKS AND PROVISIONS**
39	Monolith	2	Ground solidification
40	Monolith	27	Foundations
41	Monolith	3	Vertical and complete constructions
42	Monolith	31	Construction walls
43	Monolith	33	Columns, pier, framework
44	Monolith	34	Walls and partitions
45	Monolith	4	Horizontal constructions
46	Monolith	41	Ceilings and ceiling constructions of buildings
47	Monolith	43	Stairway constructions and ramps
48	Infrastructure	101	Sewage connection
49	Infrastructure	102	Waterway connection
50	Infrastructure	103	Heating connection
51	Infrastructure	105	Gas connection
52	Infrastructure	106	Weak current service line
53	Infrastructure	107	Outdoor water distribution

54	Infrastructure	108	Outdoor sewage
55	Infrastructure	109	Outdoor gas distribution
56	Infrastructure	110	Outdoor weak current service line
57	Infrastructure	111	Outdoor heavy current service line
58	Infrastructure	112	Outdoor lights
59	Infrastructure	113	Electricity substation
60	Infrastructure	114	Ground preparation
61	Infrastructure	115	Roads, pavements, public equipment
62	Infrastructure	117	Landscaping
63	Infrastructure	118	Fencing
64	Infrastructure	119	Traffic signs
65	Infrastructure	120	Structural walls
66	Air conditioning	240	Air conditioning
67	Heating / Cooling	731	Central heating
68	Sanitary units / Gas conduit	721	Sanitary units
69	Sanitary units / Gas conduit	723	Indoor gas conduit
70	Heavy current	210	Heavy current, lightning rod
71	Weak current	211	Weak current
72	Electric fire alarm	212	Electric fire alarm
73	Measuring and regulation	213	Measuring and regulation
74	Fire extinguishing equipment	214	Semi-stable fire extinguishing device
75	Lifts	330	Lifts, escalators

[1] Major construction works, [2] Additional construction works.

Table 1. Structure of construction units and technologies with regard to LCC.

the use of a construction in a specific location [7]. Other authors are dealing with the topic of nearly Zero Energy Buildings (nZEB) and cost-optimal level [8]. Building certification is also closely related to the issues addressed. There is a national certification system SBToolCZ in the Czech Republic. The certification systems were focused on new construction originally [9].

3. Construction project database

The LCC methodology will include a draft of Skanska construction project database. The database has already been created with Microsoft Access. It currently contains rough data of projects. The database will serve as an individual tool as well as data source for other programs. For the sake of clarity, the Table 2 shows the structure of construction units and technologies with regard to LCC.

Decisions concerning the choice of the construction technology and construction materials are not any longer based entirely on technical and economic attitudes, but are becoming increasingly influenced by life cycle cost and environmental considerations. In fact, the capability to influence the outcomes of whole life ownership is enormous during the design phase. The types of material specified, the quality of the design and the contracting method have to be chosen directly upon operation and maintenance costs. For example, choice of materials for horizontal and vertical supporting structures influences the total building time, transportation of materials and construction life span. Moreover, it influences the environmental impact of construction.

It is well documented that the majority of decisions about operating, maintenance and rehabilitation costs are predetermined at the design stage. Basically, it is crucial to establish a device at the design stage that brings together the life cycle costing, service life, environmental life cycle assessment, and risk associated with decisions taken at this stage. The proposed methodology will enable variant solutions of a construction project which will help the construction company minimize environmental impact and life cycle cost. Regarding the construction site itself, these may include air pollution caused by transportation and dust fall. The level of dust in the air may be reduced by sprinkling dirt roads within construction sites. However, water costs for sprinkling enter the total building costs, and they are not perceived as either economically efficient or ecological in terms of introducing water to the landscape in appropriate ways. Moreover, this example is set in the operational phase which is currently under minimal surveillance when investment decisions are made.

The methodology assigns economical life cycle of a construction to be 30 - 40 years. Within this period it is not necessary to renovate carry constructions or stabilize them in any way unless an emergency situation. Most construction elements are protected by finishes which need maintenance. This will be taken into account in the application. Therefore, carry elements do not appear in the following phases of the life cycle, unlike maintenance and renovation costs of

Maintenance level (LM)	Annual costs	Service life
Sub-standard maintenance	Reduction by 20 %	Reduction by 5 %
Standard maintenance	No change	No change
Above-standard maintenance	Increase by 20 %	Increase by 5 %

TABLE 2. Maintenance level.

other construction units. (Demolition of construction is not considered in the model.)

Concrete constructions may only enter the maintenance phase in case there are face concrete units which would need renovation during the building life cycle. These issues can be treated as soon as the design phase - the relation of construction demands in operational and maintenance phase. Use of concrete suggests variants of monolithic constructions or prefabricated units. Monolithic ceiling construction has ultimately different characteristics than prefabricated construction. With prefabricated units, there is higher risk of plaster ruptures or there are higher costs of plaster in such quality as to ensure consistent finish.

When considering the eventual life cycle phase - demolition - waste management would need to be taken into account, as well as transportation and/or recycling materials (such as concrete). Environmental issues and health protection should not be underestimated in this phase, as well as costs connected with these issues. An environmental LCC methodology takes into consideration not only the main cost categories (investment costs, operating costs, maintenance cost), but also external environmental costs. The environmental impact may carry consequential costs for society. In general, constructed buildings, materials and products may have environmental impacts. The processes of manufacture, transport, assembly/disassembly, maintenance and disposal linked to buildings result, for example, in emission of greenhouse gases. Subsequently, significant investment will be needed to neutralize these consequences in the future. Calculation should include the costs of greenhouse gas emissions calculated using cumulated carbon costs for the period which is analyzed (through prices of emission allowances). The LCC methodology evaluates costs of mitigating/reducing environmental impacts. As a result, the best value solution could be identified from both economic and environmental perspectives.

4. LCC CALCULATION TOOL

Life cycle cost calculation will be performed by a tool which was created by the authors of this paper. The application SW is used for the calculation of the LCC for ground structures in the Microsoft Excel operating environment. The LCC calculation includes the costs of acquisition, maintenance, service, renovation and energy consumption for designed development project options. It is a complex tool the operation of which is subject to the entry of input values to several separated topic-related spreadsheets. This separation was chosen for the sake of better clarity of data entered to the SW. The tool offers the possibility of the entry of three options of the design. Each option makes it possible to follow up to sixty years period of the project including the possibility to postpone the starting date of its operation. This time shift takes into account a postponement and the lead time of the construction works. The following sections describe individual spreadsheets that are included in the calculation of the LCC in the designed application SW.

The spreadsheet Recapitulation is used to summarize the basic identifiers of the project and clear evaluation of individual LCC calculation options. The software shows both figures and graphic representation of individual LCC sections and the total LCC of the project including key parameters of the calculation (the nominal discount rate and the monitoring period). The LCC formula components are converted to the current value in individual periods using the discount factor. The additional (comparative) indices include "LCC per 1 m^2 of the floor area", and "The ratio (budget costs/LCC)".

The spreadsheet Acquisition Costs is used for the calculation of the total acquisition construction costs of individual project options that are divided into two groups. The first category includes the structurest́ acquisition costs included in the maintenance, operation and renovation. The other category includes structures where the maintenance, service and renovation costs are expressed by a lump sum. In contrast to the above, costs of structures included to the maintenance, operation and renovation are calculated on individual basis.

The Model Parameters spreadsheet is used for the entry of key inputs for the calculation of the LCC total net present value such as the monitoring period, inflation rate, actual discount rate, anticipated postponement of the project implementation and anticipated construction period for designed options.

The spreadsheet Structural Element is used for the entry of key inputs for the calculation of the total present net value of the LCC such as the acquisition price, area, service life, maintenance costs, individual structural element service regularity and costs. Moreover, the spread sheet makes it possible to enter the maintenance level (LM) to the structural elements. It uses a specific coefficient to modify their maintenance costs and their service life (for details see the Table 2 below - starting values).

Evaluation of design options - LIFE CYCLE COST				
Project name	Example No. 1 Residential building			
Investor	-			
Place	Prague			
Construction start date	2020			
Operation start date	2024			
	Nominal discount rate	Monitoring period		
Design A	6,3%	40	years	
Design B	5,9%	40	years	
Design C	5,2%	40	years	

		Design A	Design B	Design C
LCC	Budget costs of structures included in maintenance, operation and renewal	138 105 865 CZK	88 815 765 CZK	82 941 074 CZK
	Maintenance, service and operation costs	252 102 205 CZK	310 667 714 CZK	386 146 684 CZK
	Renewal costs	47 074 401 CZK	30 842 561 CZK	33 065 534 CZK
	Other budget costs	175 548 065 CZK	226 487 692 CZK	234 297 609 CZK
	Other costs for service, maintenance and renewal	23 806 432 CZK	32 951 816 CZK	38 185 759 CZK
	Real estate insurance	8 507 050 CZK	9 152 467 CZK	10 281 494 CZK
	Total current LCC value	645 144 018 CZK	698 918 016 CZK	784 918 154 CZK
Indicators LCC	LCC per 1 m^2 floor area	45 967 CZK	54 180 CZK	49 057 CZK
	Ratio (Budget costs / LCC)	0,55	0,51	0,45

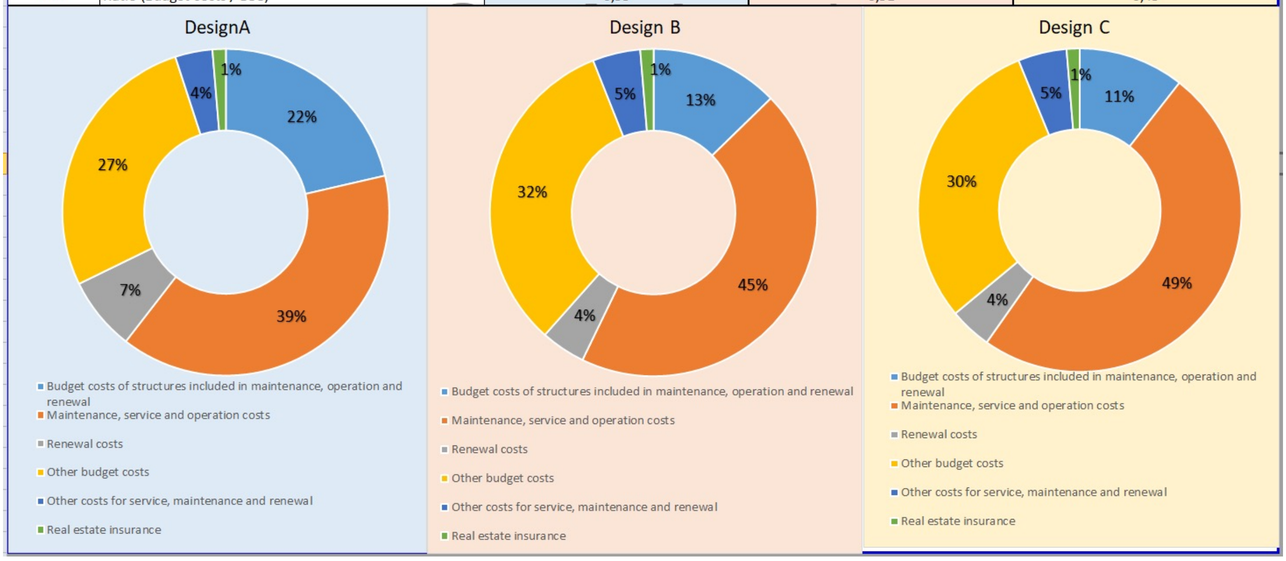

Figure 1. Evaluation of design options - life cycle cost.

The spreadsheet Operation_Energy is used for the calculation of energy price during the monitoring period for individual design options. The spreadsheet includes respective results diagrams for a better presentation. Three energy types consumption is monitored: electric power, gas and water. The calculations are based on designed energy consumption for individual technological systems included in the project (usually in the document called Building energy performance certificate (BEPC). Each option specifies eight pre-defined technologies that could be included in the project. Moreover, there is a so called optional item available that can be used for the entry of any technology whatsoever that has been added to the project. Not all technologies have to be accounted for in all cases. Sometimes only the most relevant ones from the point of view costs can be included.

On the spreadsheet Structure, there is a key calculation tool for the partial parameters of the total net present value of the LCC such as the service life including maintenance level, number of renovation cycles in the monitoring period, acquisition costs, renovation costs, maintenance costs including the maintenance level, the number of service cycles in the monitoring period and costs of service of structural elements of individual design options.

The spreadsheet Renovation, Maintenance and Operation is primarily designated for the graphic representation of acquisition costs, renovation costs, maintenance costs, service costs and operation costs broken down to individual years converted to the present value using the discount factor. A summary table is available for the service, renovation and maintenance with three maximum and minimum cost values for individual structural elements.

5. Case study

A benefit of the LCC calculation tool is the possibility to model the life cycle costs for individual design options with different input parameters. That means that the user can choose the more efficient solution for him/her. For instance, he/she may find out what will be the impacts of a more expensive but energy saving option like not only on energy costs but on the total LCC, too. Similarly, if he/she includes "maintenance" free equipment that requires higher acquisition costs, there is an apparent impact residing in the reduction of the maintenance costs but also in the value of the total costs of this project design option.

The model includes a graphic processing of data for the presentation of results to all stakeholders. The Data Recapitulation is the most useful tool for the analysis of the building LCC for any managerial decisions. This is the presentation of results and basis source document for the adoption of respective decisions in the investment project preparation phase. Any project can be integrated to the calculation model. Having added various design options, we can find out the impact of the given change on the total costs. Anticipated changes can be addressed on individual basis or as summary change sets. The given recapitulation example clearly indicate the load of the project when we take into account the maintenance, service and building operation (energy) costs. The key importance of the developed model resided in its capability to define the advantageous combination of the designed technologies for the economical operation. This is one of the most essential aspects from the point of view of the building life cycle costs.

The optimal combination of the technological units becomes an essential quantity for the entire building life cycle. The model cannot secure the presence of the complete offer of technologies as may be available on the construction market. Properly specialized and authorized designers should be aware of such information. The model can look at the technologies from the framework of the interval of performance, consumption of energy or operating costs. The combination of the most expensive systems does not guarantee the problem-free and low cost operation of the building. Chosen technologies have to be able to communicate with each other, i.e. they have to be effective. This is the most demanding part of the LCC calculation. The developed tool is therefore designed as an aid for those company workers who are in charge of the preparatory phase of the project. Given the fast development of technologies, it will be necessary to see the future results as just recommending but not binding data that are correct for the entire economic life period.

6. Conclusions

One of tools use for the assessment of the economic sustainability of designed buildings is the analysis of life cycle costs that is executed based on relevant input data on technical parameters of the building design, structural elements and equipment, related time interval of the costs that incurred. The analysis becomes an important underlying document for the decision of the investor on the identification of the best option of the building design taking into account also environmental aspects and long-term economic consequences. The analysis may be a significant marketing tool focused on the future building user to whom it presents the environment-friendly parameters and economic sustainability of the building. The evaluation of a construction project on the basis of its life cycle is included in certification systems evaluating the quality of buildings. The analysis of life cycle cost is assessed as a pertinent tool for improving the sustainability of building structures.

It is advisable that both professional and lay population realize the necessity of exploring both acquisition costs and all combined other costs during the entire life cycle when making decisions about new constructions.

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