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Life cycle cost analysis of an office building

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Abstract: The paper presents the life cycle cost structure of a newly designed office building where the costs of planning, construction, operation and maintenance are analyzed for time periods of 20 and 30 years according to current market prices and reduced to net present value. The results of the life cycle cost analysis show that for a period of 20 years, the shares of initial or capital costs and operation and maintenance costs are approximately equal. For a period of 30 years, the share of capital costs is 42.6%, and the share of operation and maintenance costs is 57.4%, which exceeds capital costs. These results confirm previous research and the significance of the operation and maintenance costs, and indicate that in engineering practice in the design stage it is necessary to analyze and calculate the total costs of the life cycle of buildings for the purpose of evaluating variant solutions.

Key words: life cycle costs of buildings, capital costs, operation costs, maintenance costs

Analiza troškova životnog ciklusa poslovne zgrade

Sažetak: U radu je prikazana struktura troškova životnog ciklusa novoprojektirane poslovne zgrade gdje su analizirani troškovi planiranja, izgradnje, uporabe i održavanja za vremenska razdoblja od 20 i 30 godina prema trenutnim cijenama na tržištu i isti su svedeni na neto sadašnju vrijednost. Rezultati analize troškova životnog ciklusa pokazuju kako je za razdoblje od 20 godina približno podjednak udio inicijalnih ili kapitalnih troškova i troškova uporabe i održavanja. Za razdoblje od 30 godina udio kapitalnih troškova iznosi 42,6% a udio troškova uporabe i održavanja iznosi 57,4% čime isti premašuju kapitalne troškove. Ovi rezultati potvrđuju prethodna istraživanja i značaj troškova uporabe i održavanja, te upućuju kako je potrebno u inženjerskoj praksi u fazi projektiranja vršiti analizu i proračun ukupnih troškova životnog ciklusa zgrada u svrhu vrjednovanja varijantnih rješenja.

Ključne riječi: troškovi životnog ciklusa zgrada, kapitalni troškovi, troškovi uporabe, troškovi održavanja

1. INTRODUCTION

The life cycle of a building refers to the building throughout its life, that is, observing the building not only in operation, but also taking into account design, construction, operation, demolition, recycling and waste disposal [1]. The life cycle of a building involves several stages. The first stage is the stage of planning, design and construction of the building, the second and also the longest stage is the stage of operation and maintenance of the building and the third stage is the stage of end of life and removal of the building [2].

The initial stage of planning, design and construction of the building is likely to have the highest impact on the total life cycle costs of the building, because decisions that will affect all future costs in the subsequent stages of the life cycle are made in the planning and design stage. The costs of operation and maintenance of the building during the operation stage can be significantly reduced by choosing the appropriate materials, structures, heating and cooling systems with higher initial construction costs. Research has shown that 70% to 80% of the building operation and maintenance costs can be influenced in the design stage [3].

Activities that have a direct impact on the length of the building's lifespan are carried out in the building operation and maintenance stage. The costs in this stage represent a large part of the costs of the life cycle of the building and the goal is to achieve a balance between the operation and maintenance costs of the building and to limit the risk of not meeting the serviceability needs and safety requirements that the building must meet [2].

The last stage is the end of the building's lifespan. It includes demolition, removal, recycling and reuse activities, and disposal of waste material to a landfill. The use and consumption of natural resources, energy and water is highly involved in all stages of the building's life cycle, which has a large and long-term impact on nature and the environment [2]. Figure 1 schematically shows the dependence of the possibility of reducing the total building life cycle costs with respect to the costs of implementing certain activities.

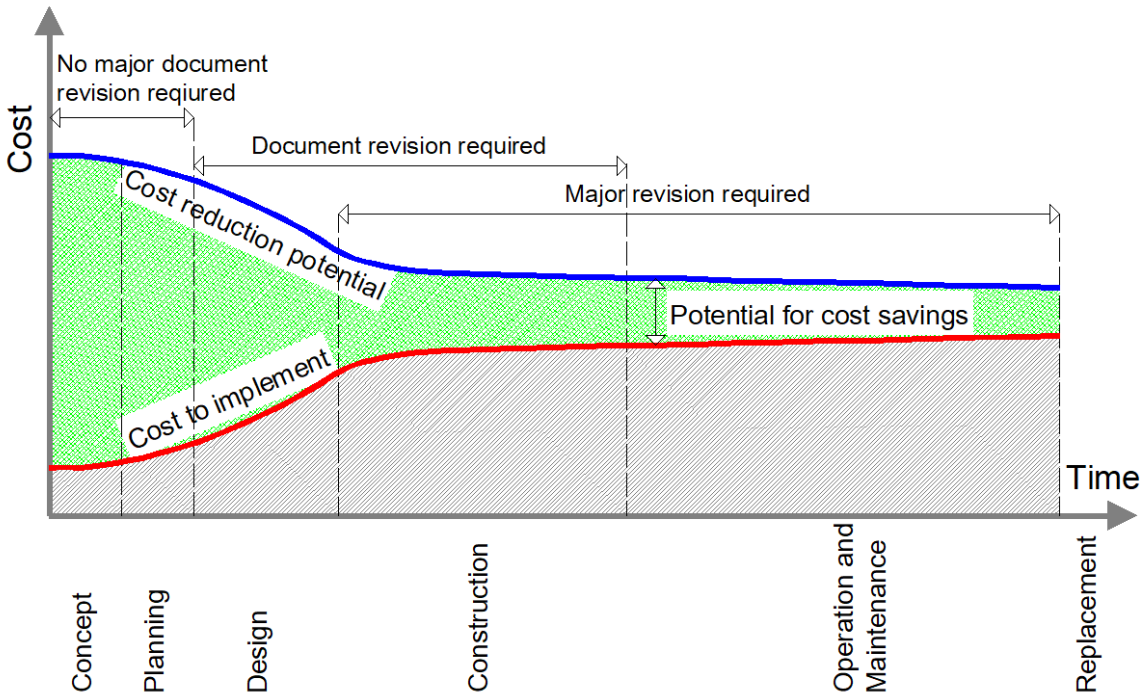

Figure 1. Scheme of the dependence of the reduction of the building operation and maintenance costs with respect to the costs of implementing certain activities [4], [5]

The highest building life cycle cost saving opportunity is in the planning stage (project conceptualizing and planning stage) without major interventions in the project documentation with low implementation costs. The design stage also enables significant cost savings in the life cycle of the building with higher implementation costs related to interventions on the project (contract) documents. The possibility of achieving savings in the building life cycle costs is significantly reduced in the stage of construction and operation of the building due to significant interventions and high costs for their implementation [2].

Until recently, all the attention of clients, architects and contractors was focused on reducing the costs of construction, and only a few of the stakeholders paid attention to reducing the costs of operation and maintenance of buildings or more importantly, reducing the total costs [6].

The paper defines activities for individual stages of the life cycle, and then analyzes the costs of planning, construction, operation and maintenance of a newly designed office building (a building that has not been built) for time periods of 20 and 30 years according to current market prices. The structure of life cycle costs as well as the results of the research are presented further herein.

2. THE STRUCTURE OF LIFE CYCLE COSTS OF A BUILDING

The term life cycle costing was first used in 1965 in a report entitled "Life Cycle Costing in Equipment Acquisition". This report was prepared by the Logistics Management Institute, Washington, D.C., and related to the procurement of military equipment [7]. Life Cycle Cost (LCC) represents the net present value of all relevant costs during the total life period of the building, including construction costs, maintenance, repair and replacement costs, operation costs and residual values [8].

The basic purpose of the life cycle costing method is to allow the selection of the optimal variant when selecting a project with regard to the total life cycle costs. Application is possible at any stage of the project, but it is most effective in the initial stages of planning and design [4]. Assessment of total costs allows us to compare alternative solutions from an economic and engineering point of view, comparing all significant options of design, construction, maintenance and operation of the building during a given period of time and selecting the optimal one [9]. Figure 2 shows the structure of the building's life cycle costs that are incurred through all life stages.

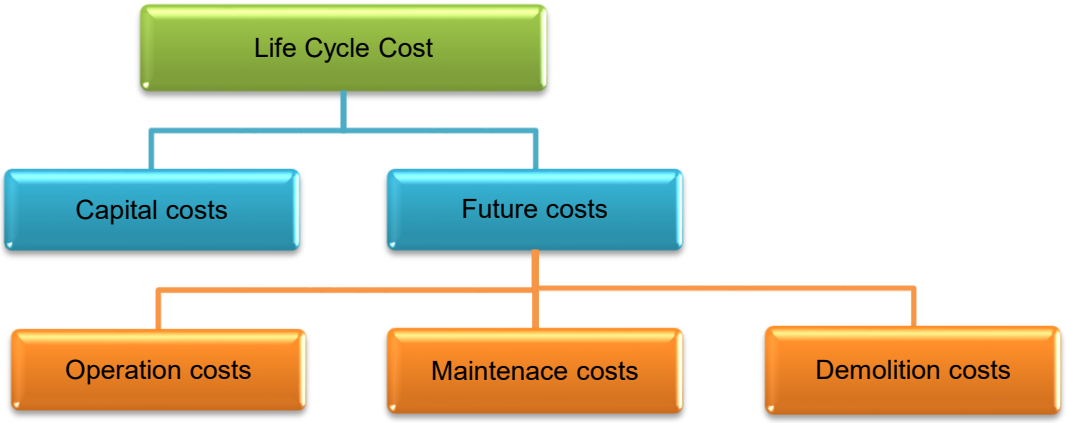

Figure 2. The structure of building life cycle costs [4], [10]

Depending on the purpose of the future building, capital costs always account for a significant portion of the total life cycle costs. These costs include costs for land acquisition, design, construction and equipment of the building and other costs related to activities in the planning, design and construction stage of the building [2]. The initial capital costs of a project are mainly those that are mostly taken into account by the client and the design team in feasibility studies, and in the absence of an estimate of total costs, they are the value that will most likely determine whether the project will start or not [11].

Future costs relate to the 2nd and 3rd stages of the building's life cycle. Building maintenance is a number of activities that ensure that constructed buildings provide adequate operation and functionality for the purpose for which they were designed. Building maintenance can be divided into preventive maintenance or planned maintenance based on the maintenance project, and reactive maintenance, or urgent or unpredictable maintenance. Preventive maintenance can be based on the time or wear condition of individual elements. It includes statutory periodic inspections, periodic works and repairs and replacement of worn-out materials and elements. Reactive building maintenance includes repairs and replacement of materials only after failure or damage has occurred, and due to this, it is almost impossible to predict all failures [3]. Figure 3 shows the structure of future building costs.

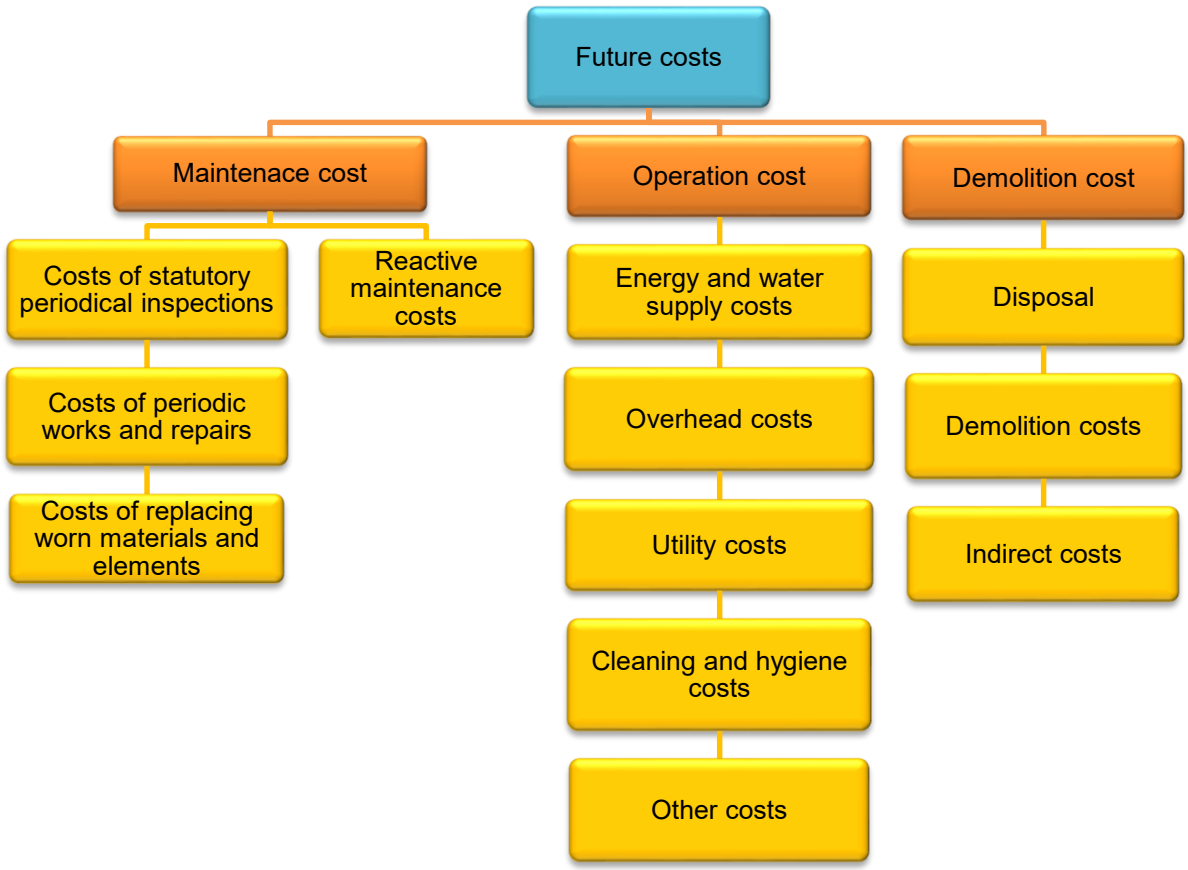

Figure 3. Structure of future building costs [3], [6]

Maintenance costs are costs that "keep" the building in a functional state, or they are costs that occur after a certain period of time to restore a certain element to its original state. It is crucial to accurately forecast and plan future costs. According to ISO standard 15686-5:2017,

maintenance costs of buildings include the costs of necessary work, materials and other related costs that arise when maintaining a certain level of serviceability of a building [12].

Operation costs are costs that occur during the entire service life of the building. Building operation costs are defined as the costs necessary for operation of the building and include operating costs of energy supply (electricity, thermal energy, energy for cooling and ventilation of space), drinking water supply costs, municipal waste and waste water removal costs, overhead costs of telephone, internet, TV, cleaning and hygiene costs, and other similar costs [3], [4].

According to ISO standard 15686-5:2017, operation costs are costs incurred by the operation and management of a building or built environment, including administrative support services. These costs may include rent, interest, insurance, energy and other environmental inspection or regulatory costs, local taxes and fees, and the like [12].

Building removal costs include the residual or sales value of the building as well as the costs incurred for demolition, removal and land (construction site) cleaning works at the end of the planned life of the building. All indirect costs arising in this stage are also included here [6].

Previous research on the life cycle costs of buildings has shown that the total costs are well worked out in theory, but difficulties arise when using them in practice. The absence of useful, reliable and consistent data needed to estimate total life cycle costs is stated as one of the main obstacles for a successful implementation in practice. If data exists, it is either inconsistent or in a form that does not allow efficient analysis. The lack of data is partly explained by the lack of acceptable standards in construction that would define the method of its collection and analysis in order to plan the total costs of projects [6].

3. ANALYSIS RESULTS OF THE OFFICE BUILDING LIFE CYCLE COSTS

A commercial building intended for office spaces that should be built on the territory of the municipality of Žepče was selected for the analysis of life cycle costs. It consists of a ground floor and three floors. The total net floor area of the building is about 2,667.00 m^2. The life cycle costs of the subject building are divided by types, specifically planning costs, construction costs, operation costs, preventive and reactive maintenance costs. Removal costs are not analyzed. All activities by individual phases of the life cycle, as well as the analyzed costs, are presented in detail in the graduation thesis entitled "Costs of planning, construction, operation and maintenance of an office building" [9].

Planning costs are the costs incurred by undertaking activities on project conceptualization (preparation of conceptual solution, preliminary investigations and development of feasibility study), land acquisition and settlement of property legal relations, preparation and review of contract documents (development and control of the main design) and obtaining construction permit. Planning costs are determined on the basis of market prices and administrative fees of competent municipal services.

Construction costs are determined based on the amount of work from the bill of quantities for construction, trade and installation works and average unit prices on the market. These costs also include the costs of professional construction supervision, technical inspection of the building and obtaining an operation permit.

A maintenance plan that defines the building maintenance activities is prepared for the subject building. Operation costs refer to heat and electricity supply costs, potable water supply costs, municipal waste and wastewater removal costs, overhead costs, cleaning costs and heating and ventilation system maintenance costs.

Costs incurred by undertaking activities related to prescribed periodic inspections, periodic works and repairs, replacement of materials and elements are classified as preventive maintenance costs. Reactive maintenance costs are assessed.

After defining all activities and costs, calculation of nominal annual costs, as well as life cycle costs for periods of 20 and 30 years is carried out. When calculating the net present value (NPV), discount rates were used in relation to the observed time periods, where a discount rate of 5% is recommended for the immediate future (1-5 years), 4% for the near future (6-25 years) and 3% for the more distant future (26-50 years) [10].

3.1 Life cycle cost analysis of an office building for periods of 20 and 30 years

When calculating the net present value, a discount rate of 3.5% was used for the period of 20 years, and a discount rate of 3.0% was used for the period of 30 years. Table 1 shows the structure and individual shares of the life cycle costs of the subject building reduced to NPV for periods of 20 and 30 years.

Table 1. Share of the life cycle costs of the subject building for periods of 20 and 30 years [9]

Cost structure	NPV 20 years (%)	NPV 30 years (%)
Planning costs	3.3%	2.8%
Construction costs	47.8%	39.9%
Operation costs	41.4%	47.7%
Preventive maintenance costs	3.2%	4.7%
Reactive maintenance costs	4.4%	5.0%
Total costs:	**100.0%**	**100.0%**

Analyzing the shares of individual types of life cycle costs in the total life cycle costs reduced to NPV for the period of 20 years, the construction costs of the subject building account for the largest share at 47.8%, followed by operation costs with a share of 41.4%. Total maintenance costs for the observed period are 7.6%. Increasing the observed period to 30 years, then the operation costs make up the largest share at 47.7%, followed by the construction costs of the subject building with a share of 39.9%. It is evident that the operating costs have exceeded the initial capital costs.

In the total operation costs, the heating energy supply costs (share 35.5%) have the largest share, followed by electricity supply costs (share 33.8%). The above results indicate that it is necessary to analyze the design solution related to thermo-technical installations, which results in the costs for the consumption of energy sources for heating and electricity. It is possible to analyze variant solutions for thermo-technical installations of the subject building that will give the lowest total life cycle costs for the observed period.

3.2 Comparison of the results of the life cycle costs of an office building

Based on previous research and literature review, examples of shares of individual life cycle cost components are presented below in order to compare the results with the analyzed office building. Table 2 shows a comparison of the results for three studies related to the calculation of life cycle costs for a 25-year period for buildings of different purposes located in Indonesia.

Table 2. Comparison and share of life cycle costs for a period of 25 years [13]

Building/purpose	Capital costs (%)	Operation costs (%)	Maintenance costs (%)
Hostel Jimbun Medika	46	26	28
University buildings of Atma Jaya Yogyakarta	43	46	11
Apartment building of University Atma Jaya Yogyakarta	42	39	19
Average	43.7	37.0	19.3

Analyzing the average values of life cycle costs (capital costs, operation costs and maintenance costs) for a 25-year period, it can be concluded that individually capital costs have the largest share of approx. 43.7%. Observing together the costs of operation and maintenance that arise during the building operation stage, their combined share amounts to approximately 56.3%, which is more than the initial capital costs.

A study of the life cycle costs of office buildings for a 40-year period in Great Britain is shown in Table 3.

Table 3. Share of life cycle costs of office buildings for a period of 40 years [14]

Number	Type of cost	Share (%)
1	Capital costs	42 %
2	Cleaning costs	20 %
3	Interest costs	16 %
4	Maintenance costs	12 %
5	Energy costs	10 %

From Table 3, it is evident that the operation and maintenance costs of office buildings for a 40-year period together make up approximately 58.0%, which is more than the initial capital costs.

Previously presented analyses of the share of individual life cycle costs (although having different periods for which the analyses were performed) show that future costs related to the operation and maintenance costs are higher than the initial capital costs. The analysis of the life cycle costs of the office building also shows that the future costs for a period of 20 years amount to approx. 49%, and for a period of 30 years 57.4%, which exceed the capital costs amounting to approx. 42.6%.

The analysis results of the life cycle costs of an office building confirm previous research and indicate that in the engineering practice in the design stage it is necessary to analyze and calculate the total costs of the life cycle of buildings for the purpose of evaluating variant solutions and making the best investment decisions. Also, planned activities related to maintenance are the basis or plan for the needs of the building owner for building management purposes.

4. CONCLUSION

Life cycle costs (LCC) represent the present value of all the costs of conceptualizing-planning and defining the project and the future costs of constructing, as well as operating and maintaining the building during its lifetime. Such an approach enables the analysis of possible savings in the building operation stage, which can be achieved by different scenarios and activities in the building design and construction stage. An analysis of the life cycle costs of an office building showed that the operation and maintenance costs for a period of 30 years exceed the initial capital costs.

In 2002, the Government of Great Britain adopted a regulation that requires an assessment of the total costs of projects (as opposed to the previous practice when bidders had to provide only a cost estimate of construction works) when making decisions related to the construction or reconstruction of public buildings such as schools, hospitals, kindergartens and other public buildings [10]. In accordance with the presented large share of the operation and maintenance costs in the total life cycle costs of the building, it is proposed to adopt legal provisions requiring the life cycle costs to be analyzed in the design stage for all public buildings that are financed from budget funds.

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