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Scenarios for Maintenance and Building Decommissioning in the Building's Life Cycle

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Abstract. The LCC analysis can be applied to assess effectiveness of construction variants or acquisition of new facilities as well as modernization of the existing ones. The authors of this paper intended to apply the LCCA method at analysing a building in the final stage of the building life cycle (grade phase). The authors decided to create and analyse costs for three scenarios assuming combination of a preventive strategy that stops the deterioration of the building's condition with three alternative end-of-life-cycle possibilities: Scenario I – preventive maintenance together with the demolition of the object; Scenario II – preventive maintenance together with the deconstruction of the object and recovery of some materials; Scenario III – preventive maintenance and sale of the object at the set point of the life cycle. An energy-efficient single-family detached residential building was chosen for the analysis. The results show that differences between LCNPV are not significant. Nonetheless, the authors suggest investors to be aware of the possibilities of the last phase of the life cycle of a building and their financial consequences.

1. Introduction

Life-cycle cost analysis (LCCA) should be applied [1] as a method used for assessing the total cost associated with the entire life cycle of a building, that is, from the concept to the end of its life to evaluate the long-term cost-effectiveness of building retrofitting investments. Life cycle costs (LCC) that are considered in the course of this analysis are related to the estimation of future cash flows. In practical terms, there is no holistic view of the actual cost of a building, which can result in failing to choose a cost-effective solution [2]. Despite numerous limitations (including determination of individual cost components), the LCC analysis can be applied to assess effectiveness of construction variants or acquisition of new facilities, as well as modernization of the existing ones. It provides transparent information on the possible consequences of the considered solutions, including cost, durability period and the reliability parameter of the facility [3].

The LCC analysis can be used both in the case of cost analysis for the entire building, or it can be limited to individual cost components. For instance, [4] describes Life-Cycle Energy Analysis, focusing solely on the analysis of energy costs of a construction project, while [5] concentrated on the assessment of a partial product life cycle from resource extraction (cradle) to the factory gate (that is, before it is transported to the consumer).

Similarly to the latter research, the authors of this paper intended to apply the LCCA method at analysing a building, yet they did not limit it to the cradle-to-factory-gate stage but prolonged it to the final stage of the building life cycle (grade phase).



2. Scenarios of the life cycle of a building or its components

In order to perform the analysis, scenarios of the operation and building decommissioning phases created especially for this purpose were used. The definition of a life cycle scenario and literature examples are presented below.

The life cycle scenario is a set of defined functions and processes that are arranged in a logical sequence and whose effects lead to the achievement of a goal set in the adopted product management strategy of the life cycle [6]. The author analyzes three scenarios that have the same product life cycle time and identical level of total expenditure incurred throughout the life cycle of the road surface under study. The author only diversified the allocation method and diversification of the level of inputs in the individual phases of the life cycle of a building.

Zayed, Chang and Fricker [7] proposed different rehabilitation scenarios for painting steel bridges. The authors employed an economic analysis (EA), which is a deterministic method, and the Markov decision process (MDP) to choose the best scenario for the use of bridge coatings. They discussed these rehabilitation scenarios which correspond to particular maintenance strategies of paint coatings of steel bridges in the operation phase. The scenarios assumed lack of any repairs until the end of the painting life cycle and a complete repainting or making periodic repairs in predetermined dates, or spot repairs after reaching the assumed condition of the coating. The authors' research led to the selection of the best scenario involving periodical repairs of the paint coating every 10 years.

Another approach to the maintenance strategy that suits the types of maintenance is described by Frangopol, Lin and Estes [8]. The methodology was illustrated on reinforced concrete T-girders of the motorway bridge. The authors assumed two maintenance strategies in their research, namely, a strategy for preventive deterioration of the state of construction (preventive maintenance) and a repair-oriented strategy (corrective maintenance). Optimization performed by the authors is based on minimizing the expected total life cycle cost which includes the initial cost, preventive maintenance of the structure, costs of inspection, repair and failure. Research shows that a time-varying inspection and repair strategy is more economical than inspections conducted at regular intervals.

The authors of this paper decided to complete the description of the presented scenarios with the final phase related to the end of the life cycle of a building, called the withdrawal phase. Most often the decommissioning phase ends in the deconstruction of the building and the management of deconstruction materials, called construction waste. This approach, strongly embedded also in Polish conditions, is commonly called from cradle-to-grave approach and, regardless of the subject of the research; it leads to the deconstruction of the building component or the building.

Construction works involving demolition of an existing building should be carried out in the end of the life cycle of a building, when the technical condition of the building may represent a threat to the safety of people and property. Naturally, the deconstruction can be performed much earlier if the owner sees the desirability of such undertaking or its economic profitability. According to the Polish Construction Act, protective and deconstruction work may begin before obtaining a demolition permit or before notification, if it is intended to remove an immediate threat to the safety of people or property. The commencement of such work does not exempt from the obligation to immediately obtain a permit for deconstruction or notification about the planned deconstruction of a building.

Sobanjo [9] in his work writes about the life cycle analyses, distinguishing the following phases: initial, rehabilitation, sale/demolition, operating and maintenance costs. In the final phase, two options are provided: deconstruction and sale of a building. The authors of [10] called the last phase the 'phase of withdrawal' assumed that, as in the previous case, it can be accomplished by deconstructing or selling the object.

In Wong, Perera and Eames [11], it was determined that the alternative completion of the life cycle of a building is its secondary sale together with the area on which it is located. This approach allows for the secondary use of the building for other purposes or the re-use of recycled building material. Such approach is called "from cradle-to-cradle approach". Therefore, the authors of the paper took into account the residual value of the object, that is, the estimated resale value and costs of building disposal, machinery and equipment, as well as land and other assets at the end of their lifetime.

Another possible solution to end the life cycle is the “from-cradle-to-gate” approach. This approach is often used in the case of building materials and components, and less often in the case of construction work. Takano, Winter, Hughes and Linkosalmi [12] note that such an approach is characterized by performing the analysis of the life cycle of the research subject only to a certain stage. Analyses with this type of approach may end, for example, after processing raw materials making up the finished element or at the stage of its production. The analysis would cover only the two initial phases of the life cycle of the building component, that is, the programming (cradle) and implementation (gate) phases.

3. Selected scenarios

Analyzing Polish and international scientific literature on creating scenarios of the life cycle, the authors decided to create and analyze costs for three scenarios assuming a combination of a preventive strategy that stops deterioration of a building's condition with three alternative end-of-life-cycle possibilities:

- Scenario I – preventive maintenance together with the demolition of the object;
- Scenario II – preventive maintenance together with the deconstruction of the object and recovery of some materials;
- Scenario III – preventive maintenance and sale of the object at the set point of the life cycle.

These are not the only possible scenarios. The intention of the authors was to indicate the most common scenarios in which the main differences concern the last phase of decommissioning. Deconstruction costs of a chosen building are shown in two versions without recovery and with the recovery of some materials. In the third option, the residual value of the construction object was estimated for resale.

3.1. Scenario I – demolition of the building

Building decommissioning may involve either demolition or deconstruction of the building. In the case of deconstruction, the opportunity to recover the materials or even entire fragments of the building used for construction of a given property exists, while demolition is equal to the complete decommissioning of the object. Demolition of the building is usually done with the use of heavy machinery (bulldozers, cranes, excavators) and, depending on the characteristics of the building, usually takes from few to several days.

The cost of demolishing a specific object depends on many factors. The most important ones include the volume of the building and the thickness of the walls resulting directly from the building material. Other factors determining the cost of demolition involve: the type of building structure; the degree of complexity associated with the demolition works; the amount of building remains and the distance to transport the debris.

These costs must also incorporate the cost of waste transporting. The price depends primarily on the distance from the dump site. The prices for rubble removal depend to a large extent on the amount of waste. The price of the majority of recipients is calculated on the basis of the container capacity but it may also depend on the specificity of the waste. The cheapest solution is the transportation of uncontaminated debris (the so-called pure debris). Debris and building residues disposal can generate higher service prices.

3.2. Scenario II – deconstruction with material recovery

To recover some of the construction materials, manual deconstruction is recommended, that is, without the use of heavy machinery. It is rather awkward and time-consuming; however, it allows recovering quite a large amount of building material, which can be sold or used to construct a new

building. Sometimes, though, a demolition company undertakes a demolition work in exchange for the possibility of recovering building materials. Manual deconstruction makes it possible to recover materials for reuse. Construction materials in good condition, such as bricks, wood, roof tiles or steel beams can be reused for a new construction, while some finishing materials, for example thick oak floorboards, may be reused after renovation or processing. Concrete (concrete rubble) in turn, is reused when constructing ground floors or paving the surfaces on the building plot.

3.3. Scenario III – sale of the building

For the purpose of the resale of a building, its valuation is necessary to determine the market value of the property. It should be done by a certified property valuer who can use the following approaches to determine the value of the real estate: a comparative, income, cost and mixed one.

One of the most commonly used approaches is the comparative one. It applies to the property market value which is obtained if there is a market for similar properties that were in the market in the past two years. The approach involves the following methods:

- Pair wise comparison – 3 to 5 similar properties are taken into account. It consists in comparing the property that is the subject of the valuation, the features which are known, successively with similar properties which were traded on the market and for which transaction prices, transaction conditions and components of these properties are known.
- Adjusting the average price – several properties are taken into account. It consists in determining the market value of the valued property on the basis of at least several representative properties accepted for comparison, being the subject to the sale transaction. The determination of the market value of the property involves adjusting the average market price obtained from this set, using the ratios assigned to the relevant market features of the property.
- Statistical analysis of the market – it is not used in practice, but theoretically it is applied when exist quite a large group of similar properties being bought and sold on the market. These may be, for example, municipal flats intended for sale, land for which the fees for perpetual usufruct or other mass-valued properties which should be reconstructed.

4. A sample LCC analysis based on maintenance and decommissioning scenarios

An energy-efficient single-family detached residential „Garda” building, without a cellar, made of SILKA E24 blocks (data according to Sekocenbud BCO 1/2018; 1110-131 (1173)) was adopted for the analysis.

The basic parameters of the building are:

- Building area – 150.96 m²
- The usable area of apartments – 151.65 m²
- The area of the garage – 22.49 m²

Preventive maintenance costs at the same level were included in all scenarios. Preventive maintenance activities consist of work and repairs that are repeated at approximately the same time intervals, depending on the service life of the facility or its structural elements. Examples include: changing filters in HVAC equipment, smaller painting projects and similar tasks. Those costs are included in calculation of annual and periodical operating costs.

In scenario I, total demolition of the building was assumed. To estimate the demolition cost, the quantities of the main structural elements were listed. Then, based on the price guide “Sekocenbud 9/2018 I quarter of 2018 Bulletin of prices for renovation, construction and historic works”, the unit costs of demolition work and the costs associated with the debris transport were determined. It was assumed that the dump site is located at a maximum distance of 5 km from the location of the

building. A maximum of 100 m³ of debris was assumed to be created from the demolition of the building. The calculations are presented in Table 1.

In scenario II, it was assumed that the investor would not incur costs associated with the deconstruction - deconstruction work was performed partially in exchange for the recovered materials.

In scenario III, the cost of the property was estimated using a comparative approach (pair wise comparison). The price for which the property could be resold, taking into account its previous 30 years of use, was set at EUR 41,574. The estimation used statistical data of buildings of a similar age, size, and function. The value of income included the price of a land plot.

Table 1. Demolition costs.

Type of work	M.U.	Quantity	Unite price	Cost [EUR]
Concrete and reinforced concrete elements, including:				
Concrete foundations	m ³	6.00	73.38 EUR/m ³	440.28
Reinforced concrete foundations	m ³	19.00	115.57 EUR/m ³	2,195.83
Reinforced concrete wall	m ³	3.00	157.85 EUR/m ³	473.55
Masonry elements, including:				
Underground walls	m ³	12.00	24.36 EUR/m ³	292.32
Above-ground walls	m ³	50.00	21.04 EUR/m ³	1,052.00
Wooden elements (roof structure)	m ²	194.00	1.17 EUR/m ²	226.98
Removal of debris	m ³	100.00	2.94 EUR/m ³	294.00
TOTAL COST		4,974.96		

Table 2 summarizes the data for determining the LCC in the three scenarios.

Table 2. Data assumed for analysis.

PARAMETER	SCENARIO 1	SCENARIO 2	SCENARIO 3
The manner of building decommissioning	Building demolition	Building deconstruction with recovery of materials	Sale of the building
Life cycle = ESL [years]	30	30	30
Initial costs [EUR]	112,898	112,898	112,898
Annual operating costs [EUR]	2,664	2,664	2,664
Periodical operating costs after year [EUR]	10 th 4,587	4,587	4,587
	20 th 4,587	4,587	4,587
Withdrawal costs [EUR]	4,975	3,730	-
Income [EUR]	-	-	41,574

An example of a complex method is the analysis of the effectiveness of investments in their life cycle (LCNPV) based on discounted cash flow with consideration of environmental impacts. The basic calculation formula is as follows:

$$LCNPV = \sum_{i=0}^{ESL} \frac{CF_i}{(1+r)^i}, \quad (1)$$

where: CF_i - cash flow in i -th year, ESL - estimated service life in years, i - subsequent year, r - discount rate.

Table 3 shows the LCC calculation results for three scenarios for different discount rates. Determination of an appropriate discount rate is a key component in any NPV analysis. Private discount rates are typically set based on opportunity costs, using short to mid-term investment rates that the organization would have earned reflecting investment earnings actually available on the market for the period under analysis and at risk levels the organization is willing to tolerate. In analysis three most often used discount rates in Polish condition are the considered ones.

Table 3. LCC calculation results.

	SCENARIO 1			SCENARIO 2			SCENARIO 3		
The manner of building decommissioning	Building demolition			Building deconstruction with recovery of materials			Sale of the building		
Discount rate [%]	10	8	6	10	8	6	10	8	6
LCNPV [EUR]	-127,979	-135,677	-145,731	-127,929	-135,572	-145,537	-125,597	-131,453	-138,147

The results show that the best results can be achieved for the Scenario 3, but the differences in LCNPV are not significant. It can also be seen that the higher the discount rate, the lower the LCNPV. For discount rate of 10 % the difference between the best and the worst scenarios is only EUR 2,382. For the discount rate of 6% the difference is EUR 7,584.

5. Conclusion

A sample of LCC analysis based on maintenance and decommissioning scenarios for an energy-efficient single-family detached residential building has been proposed in the article. The data for determining the LCC was collected and the results were presented using three scenarios: preventive maintenance together with the demolition of the object; preventive maintenance together with the deconstruction of the object and recovery of some materials and preventive maintenance and sale of the object at the set point of the life cycle.

The authors suggest investors to become aware of the possibilities for the last phase of the life cycle of a building and their financial consequences.

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