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Data Flow in Relation to Life-Cycle Costing of Construction Projects in the Czech Republic

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Abstract. Life-cycle costing is an important part of every construction project, as it makes it possible to take into consideration future costs relating to the operation and demolition phase of a built structure. In this way, investors can optimize the project design to minimize the total project costs. Even though there have already been some attempts to implement BIM software in the Czech Republic, the current state of affairs does not support automated data flow between the bill of costs and applications that support building facility management. The main aim of this study is to critically evaluate the current situation and outline a future framework that should allow for the use of the data contained in the bill of costs to manage building operating costs.

1. Introduction

Life-cycle costs (LCC) are among the tools used to assess investment projects (including, but not limited to, construction projects) that take into account the overall costs during the whole life cycle (WLC) of a project. The life cycle of built structures is divided into four phases – pre-investment, investment, operation, and demolition – with different costs associated with each phase. The pre-investment and investment phases are associated with high initial costs during a relatively short period of time, while the operation phase, which is the longest phase of the life cycle, comes with relatively low annual costs. However, as a part of the overall life-cycle costs, these operational costs i.e. replacement, repair, and maintenance costs may, in total, exceed the initial cost of the structure [1, 2]. As project success or failure should be reflected with respect to the whole project life cycle by considering all the process groups in the project, LCC represents significant element is this context [3].

Using the LCC indicator can help find the most suitable construction design that will help keep the costs as low as possible during the given period. The LCC is often complemented by the building carbon footprint indicator, as construction – as well as any activity that uses energy – leads to CO2 production [4, 5]. E.g., when speaking about the operational costs of renewable energy systems, they can be much lower than traditional systems while investment costs are usually higher [6]. The single most important factor affecting these indicators is the design, which is developed during the pre-investment phase of the project. The designer or architect should strive to find the most economical solution as regards the structure and the materials used. For example, Ellingerová [7] points out that future costs of operation are increasingly more difficult to change with the more advanced phases of the project or construction. Currently, there is no tool in the Czech market for easy and quick calculation of the LCC of a given construction project. This is despite the fact that since 2016, the legal regulations have stipulated that it is preferable to assess public procurement projects based on their economic profitability – that is, not only on the bid price, but also on other economic parameters, including the life-cycle costs [8].

The calculation of LCC is very simple and can be used in different phases of the construction project [4]. Problem can occur with the lack of data (partial or full) required for the LCC analysis. Generally, data can be grouped into occupancy data, physical data, performance data, quality data, and cost data [9]. The number and cost of repairs during the expected life of the built structure is based on the life of its individual parts and budget purchase price, while maintenance costs are based on pre-determined costs per unit of the individual structural components, using discounted cash flows. The methodology for the calculation is provided by a European standard [10]. The purchase price is given by the budget and the period is based either on the life of the structure or on a specified period of time, based on the way the investment is being assessed. However, there is a problem with the data from the operation phase of a built structure. The cost and extent of repairs and maintenance or the frequency of replacement of individual parts are difficult to determine, but very important for the calculation. In public procurement, the data has to be incontestable and always current. The paper therefore aims to propose a model of deriving information from the operation phase of a built structure about the individual structural components (functional parts). Such model has an ambition to serve as a tool facilitating the recording, monitoring and predicting of costs related to the functional parts, which represents an important area of LCC. In such way, proposed model could provide relevant information for investment decision-making during early phases of the project in order to contribute to its high efficiency.

2. Definition valid in the Czech Republic

As mentioned above, the calculation of LCC is stipulated by a European standard, also corresponding to the formula that is to be used for public procurement [10]:

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

Where:

C_t…all costs as equivalent cash flows in year t;

r…discount rate;

t…analysed year (t=0, 1, 2…, T);

T…length of life cycle in years.

There are other relationships that can be used to calculate LCC, such as the one suggested by Kishk [11]. Compared to the formula cited above (1), the main difference is in the discounting of regular and irregular costs. The Bromilow and Pawsey cost model can serve as an example:

$$LCC = C_{0i} + \sum_{i=1}^{n} \sum_{t=1}^{T} \frac{C_{it}}{(1+r_{it})^t} + \sum_{i=1}^{m} \sum_{t=1}^{T} \frac{C_{jt}}{(1+r_{jt})^t} - \frac{D}{(1+r_d)^T}; \tag{2}$$

Where:

C_{0i}…acquisition costs at the time t=0, including all designs, construction, fees, and other costs related to the acquisition;

C_{it}…regular annual costs, such as maintenance, cleaning, power, security, etc.;

C_{jt}…costs at specific times – repairs, replacements, etc.;

r_{it}, r_{jt}…discount rates for periodic and non-periodic costs;

D…value of the property at disposal after accounting for demolition costs;

r_d…discount rate for D.

The main feature of such model is the classification of maintenance activities into non-annual recurring costs, and costs that remain continuous.

In spite of cost model (2), El-Haram et al. [12] proposed a whole life-cycle model for calculation of each building element:

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$$WLC = C_C + (\sum_{i=1}^{n}(\sum_{j=1}^{m} O_{Cj}) + \sum_{i=1}^{n}(\sum_{j=1}^{m} M_{Cj}) + \sum_{i=1}^{m} R_{Ci}) \pm D_C; \quad (3)$$

Where:
WLC…whole life-cycle costs;
C_c…construction cost;
O_c…operating cost;
M_c…maintenance cost;
R_c…replacement cost;
D_c…disposal cost;
n…number of years (expected life of the project or period of analysis);
m…number of operating and maintenance tasks;
k…number of replacements.

Such model (3) can be used to estimate WLC of an individual building element, therefore it can be used for calculation of LCC. As authors stated [12] "to estimate the WLC of a building, other costs should be added such as the land acquisition, professional fees, bid costs, etc."

All models of life-cycle costs of a built structure use, in principle, the same values:

- The period in question, which is equivalent to the expected life of the built structure or, as mentioned earlier, to a period specified by the investors, which can correspond to the recovery of their investment. The expected life of built structures in the Czech Republic was described by Kupilík [13]; for example, a masonry built structure is expected to have a life of 100 years.

- The discount rate used when modelling LCC is up to the individual investors, but it should correspond to the rate of return of other similar projects or requirements for specific types of public projects (a rate of about 5% is often used in the Czech Republic [14]).

- Costs incurred during the life cycle (see Table 1) [10].

In this relation, the question is how frequent and how high these costs will be arising. Every structure has different requirements when it comes to maintenance, repair, or expected life. As a general rule, one of the main factors that have an impact on the expected life is the material used to build the structure. Other factors include the quality of production and construction or maintenance. Currently, there is no regulation or standard in the Czech Republic that would determine the data needed for life-cycle cost calculation in the construction industry.

Table 1. Categorization of the life-cycle costs of a built structure; source: [10]

LIFE-CYCLE COSTING (LCC)				
Construction Costs	**Operation Costs**	**Maintenance Costs**	**Replacement Costs**	**Handover Costs**
- Design – professional fees - Temporary works, site clearance or groundwork - Construction, fitting out, commissioning - Adapting, refurbishment - Externals and infrastructure works - Project management - Fixtures, fittings, furnishings, and loose equipment	- Rates - Insurance - Energy costs for heating, cooling, power and lighting and water costs - Facilities management cost, health and safety management, cleaning and waste management - Annual regulatory costs	- Annual planned service and maintenance regime - Repairs, routine component replacement, and minor refurbishment - Downtime and business disruption costs	- Restoration of the main elements or systems - Downtime and business disruption costs - Unanticipated costs resulting from legislation - Adaptation, refurbishment, fitting out, commissioning, validation, and handover	- Final condition inspection and associated fees - Additional cost of meeting the assets' contractual performance and condition criteria for handover - Provision of spares and consumables

Marková examined the issue of LCC calculation in [15]. Through a survey, she defined the cycles and costs of repairs, maintenance, and replacement of functional parts. The division of a built structure into functional parts is similar to the division into construction parts in TSKP (Classification of structural components and works in construction for the Czech Republic); however, construction parts (TSKP), as opposed to functional parts, are adapted to the content and value of construction works, but not to the structures themselves. A sample of functional parts together with the information needed for the LCC calculation is given in Table 2.

Table 2. Approximate data for calculating the LCC of a built structure for surface items [15]

Code	Functional part (FP)	FP life min. [year]	FP life max. [year]	Repair cycle [year]	Extent of repairs [%]
5110	Internal plaster	100	-	30	50
5120	Internal paint	5	15	-	100
5130	Internal tiling	20	80	20	10
5140	External plaster, insulation	30	60	30	20

The example above shows that the range of the data is rather wide and that there is no distinction based on the materials used. For example, the functional part "5140 External plaster, insulation" could use several different materials for insulation, such as extruded polystyrene (XPS), expanded polystyrene (EPS), or mineral wool, with mineral wool having a longer life than expanded polystyrene. As a result, this level of detail in the data is not sufficient for a more accurate calculation of LCC.

If LCC is to be accurate enough, the data itself needs to be more accurate and detailed. In other countries, such as Norway, there are such databases of data, but these are bound to cost-estimating software [16]. In the Czech Republic, price databases are structured differently and the local construction industry uses different processes, which would make the Norwegian model difficult to adopt.

3. Suggested framework of data flow for LCC modelling and management

A suitable solution for the Czech construction industry seems to be creating a three-step framework of data flow for LCC modelling and management: 1) aggregating the individual items found in the price database into functional parts of a built structure; 2) obtaining information about the life, frequency of repairs, maintenance, and related costs for the individual structural components; and 3) transferring all the required input data into a model for LCC calculation and evaluation.

3.1. Aggregation of price database items into functional parts

As the Czech price database is much larger than databases in other countries (around 100,000 items), assigning individual data to each item and subsequent management of the set would be highly inefficient. A desirable solution, therefore, is to create a database based on the categorization into functional parts, which were suggested in [15]. In this way, each item in the price database would only contain the information about which item from the LCC database bears the related costs (see figure 1).

Item code (TSKP)	Item description	UoM	Item price	LCC code
622211021	Applying contact insulation to external walls – polystyrene boards, thickness up to 120 mm	m_2	P_1	5141
283759390	*EPS facade boards 70 F 1000 x 500 x 120 mm*	m_2	P_2	5141

LCC code	Functional part (FP)	Exported price	Replacement costs	Repairs costs	Maintenance costs
5141	External insulation – expanded polystyrene	$P_1 + P_2$	...	...	...
5142	External insulation – mineral wool	...	...	...	...
5143	External insulation – other materials	...	...	...	...

Figure 1. Example of price database items aggregation into functional parts [by the authors]

In this way, the unit prices of selected items from the price database (works and related material) will be aggregated into the individual functional parts. Figure 1 shows an example of such aggregation for functional part 5141 "External insulation – expanded polystyrene".

3.2. Obtaining information about life, frequency of repairs, maintenance, and related costs for the individual structural components

Currently, there is a lack of available data about the life, frequency of repairs, maintenance, and related costs, all of which are required for LCC calculation. This data should be part of facility management software, which, in its turn, should be used by any property management entity. The government of the Czech Republic, as the biggest owner of property in the country, uses this tool, even though only to a limited extent. It is the CRAB register (Central Register of Administration Buildings), which includes information about the projects' legal relationships, relocation requests, and economic data [17]. As a part of the economic data, the database contains revenue and costs related to each building. However, there is no further breakdown of the costs into individual components. If the system included the items from the LCC databases, with individual building managers entering more detailed economic data (dates, purpose, amounts, etc.), the resulting database could eventually be used not only for public procurement, but also in the private sector. Figure 2 shows the proposed information that should be included in the facility management software and the transformation of this data into a form usable for LCC calculation.

LCC code	Functional part (FP)	quantity	UoM	..	Ø cycle of replacement (year)	Ø cost of replacement (CZK/1m2)	Ø repair cycle (year)	Ø cost of repairs (CZK/1m^2)	Ø cycle of maintenance (year)	Ø cost of maintenance (CZK/1m^2)
5141	External insulation – expanded polystyrene	Q	m^2	..	*CycleRM*	*CostRM*	*CycleR*	*CostR*	*Cycle M*	*CostM*

Detailed FP 5141:

Activity	Date	Activity description	Costs per m^2 (CZK)	Total costs (CZK)
Construction	D	First use in built structure	C	Q * C
Maintenance	dm_1	Regular maintenance	M_1	Q * M_1
Maintenance	dm_2	Regular maintenance	M_2	Q * M_2
Repair	dr_1	Contact insulation system repair	R_1	Q * R_1
Maintenance	dm_3	Regular maintenance	M_3	Q * M_3
Repair	dr_2	Contact insulation system repair	R_2	Q * R_2
...	…	…	…	…
Replacement	drm_1	Complete replacement of contact insulation system incl. design	RM_1	Q * RM1

Figure 2. Example of data structure in facility management software [by the authors]

CycleRm, CycleR, and CycleM, which express the average cycles of replacements, repairs, and maintenance, respectively, are calculated using the formulas below:

$$CycleRM = \frac{(D-drm_1)+\sum_{i=2}^{n}(drm_i-drm_{i-1})}{n} \quad (4)$$

$$CycleR = \frac{(D-dr_1)+\sum_{i=2}^{n}(dr_i-dr_{i-1})}{n} \quad (5)$$

$$CycleM = \frac{(D-dm_1)+\sum_{i=2}^{n}(dm_i-dm_{i-1})}{n} \quad (6)$$

where:
D…date of construction;
drm_n, dr_n, dm_n... date of the *n*th replacement (RM), repair (R), or maintenance (M);

CycleRm, *CycleR*, and *CycleM*, which express the average costs per 1 unit for replacements, repairs, and maintenance, respectively, are calculated using the formulas below:

$$CostRM = \frac{\sum_{i=1}^{n} RM_i}{n} \quad (7)$$

$$CostR = \frac{\sum_{i=1}^{n} R_i}{n} \quad (8)$$

$$CostM = \frac{\sum_{i=1}^{n} M_i}{n} \quad (9)$$

where:
RM_n, R_n, M_n…unit costs of the *n*th replacement (RM), repair (R), maintenance (M).

3.3. Transferring the data into an LCC calculation and evaluation model

Figure 3 shows the data flow between the individual software programmes. Firstly, all the items with the same LCC database code are aggregated in the cost-estimating software (see bullet point 1 – data aggregation) and their acquisition price is uploaded. Afterwards, information about replacements, repairs, and maintenance is uploaded from the facility management software of an existing building. This data is then used for calculating the life cycle of a built structure, which can be used to evaluate the effectiveness of the planned investment as well as for estimating the dates and costs of replacements, repairs, and maintenance.

COST-ESTIMATING SOFTWARE

Item code	Item description	UoM	Item price	LCC code
622211021	Applying contact insulation to external walls – polystyrene boards, thickness up to 120 mm	m^2	P_1	5141
283759390	*EPS façade boards 70 F 1000 x 500 x 120 mm*	m^2	P_2	5141

LCC CALTULATION

LCC code	Functional part (FP)	Exported costs	Replacement costs	Repairs costs	Maintenance costs
5141	External insulation – expanded polystyrene	P_1+P_2	C_{rm}	C_r	C_m

FACILITY MANAGEMENT SOFTWARE

EXISTING BUILT STRUCTURE

External insulation – expanded polystyrene	
LCC code	5141
Quantity	Q
UoM	m^2
Cycle of replacement (year)	*CycleRM*
Cost of replacement (CZK/1m²)	*CostRM*
Repair cycle (year)	*CycleR*
Cost of repair (CZK/1m²)	*CostR*
Cycle of maintenance (year)	*CycleM*
Cost of maintenance (CZK/1m²)	*CostM*

NEW BUILT STRUCTURE

External insulation – expanded polystyrene	
LCC code	5141
Quantity	Q
UoM	m^2
Estimated data	
1st year of maintenance	dm_1
Cost of 1st maintenance (CZK)	M_1
1st year of repair	dr_1
Cost of 1st repair (CZK)	R_1
…	…

Figure 3. Example of data transfer between different software programmes [by the authors]

C_{rm}, C_r, and C_m, which are the component parts of LCC – the cost of replacement, repairs, and maintenance, respectively – are calculated using the formula (1). The formulas for the individual parts are as follows:

$$C_{rm} = \sum_{t=0}^{T} \frac{RM_t}{(1+r)^t} \tag{10}$$

$$C_r = \sum_{t=0}^{T} \frac{R_t}{(1+r)^t} \tag{11}$$

$$C_m = \sum_{t=0}^{T} \frac{M_t}{(1+r)^t} \tag{12}$$

where:

RM_t…cost of replacements as equivalent cash flow in year *t*;

R_t…cost of repairs as equivalent cash flow in year *t*;

M_t…cost of maintenance as equivalent cash flow in year *t*;

r…discount rate;

t…analysed year (*t*=0, 1, 2…, *T*);

T…length of life cycle in years.

4. Conclusions

The suggested system of transferring data between the individual software programmes is general and can be used for all types of cost-estimating and facility management software. It is based on keeping the structure of data as used in LCC both in the cost-estimating software and in the facility management software. The calculated LCC of a built structure can be used in two ways. First, it can be used to find the most cost-effective construction design; second, it can be used to plan operation costs during the operation phase of the structure's life cycle, so that all replacements, repairs, and maintenance costs are effectively managed.

This study only takes into account operation costs related to the individual structural components and disregards other costs, such as cooling or heating. The model presented in this paper therefore contributes to a more effective management of operation costs related to the life and quality of the structural components of a built structure.

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