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Analysis of the Cost of a Building's Life Cycle in a Probabilistic Approach

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Abstract: In the article the costs of alternative roofing techniques in the life cycle of the building were calculated. The calculations were made in accordance with ISO 15686-5 standard "Buildings and constructed assets – Service life planning – Part 5: Life-cycle costing", using normative durability periods and minimum period of annual consumption of individual building elements to determine the durability of building components. The normative periods are valid in Poland in relation to the valuation of buildings. Probabilistic costs in the life cycle of ceramic, metal and bituminous coatings were analysed. The probability density distributions were assumed: beta for pricing factors and normal for the interest rate. Calculations were carried out for the periods of 100 years of operation of coverings, taking into account the costs of replacement and utilization. As a result of the calculations, the life cycle costs of alternative coatings with probabilities from 5 to 95% were obtained.

Keywords: LCCA, statistical calculations, simulation-based costing

1 Introduction

Life cycle cost analysis (LCCA) is among others a tool for determining the most cost-effective option among the various competing alternatives. All costs of the user are taken into account in the LCCA of construction projects, starting from the purchase of land through the design process, erection of the building, costs related to the use such as: management costs, periodic inspections, repairs, repairs, replacement of instrumentation and infrastructure related to the object. All costs in the analysis are discounted to the current value known as the net present value (PV). The LCCA analysis uses two approaches: Deterministic (DBC deterministic-based costing) and probabilistic (SBC simulation-based costing). It was observed that all variables used in the calculations are characterized by variability. You can only approximate the scope and cost of the renovation that would take place in 40 years. The article proposes a method for calculating the life cycle costs of a building in the SBC LCCA probabilistic approach. The proposed procedure for calculations is described. Cost-effectiveness plays a key role in any construction project. Life cycle cost analysis (LCCA) is a method of determining the total cost of a construction project in the expected period of use, including operating and maintenance costs. LCCA in the deterministic approach can be improved using alternative modern probabilistic techniques. Probabilistic calculations in which the minimum, average and maximum values are defined with specific distributions are closer to the actual values.

2 Probabilistic Life Cycle Cost Analysis

The choice of building materials when designing a building has a major impact on costs. An analysis of construction and renovation costs has been carried out over a period of 100 years. The SBC LCCA method assumes that all data used for calculations have probabilistic values. It was observed that all data are highly volatile. It was assumed that there are no grounds to claim that the result of life cycle cost calculations of individual building elements, as well as of the entire building, will be a discrete value. The article proposes a method of calculating the life cycle costs of a building in SBC LCCA. The proposed calculation procedure was described. Probabilistic calculations, in which minimum, average and maximum values are defined with specific distributions, are closer to real values. They can form the basis for information on the life cycle costs of

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a building. The method of SBC LCCA calculations is presented on the example of roofing material selection. Three types of materials in their life cycle were compared: clay roofing tiles, steel roofing tiles and roofing membrane.

3 SBC LCCA calculation

The collection of data needed for calculations is the most important and labour-intensive element of the method. It is necessary to determine the minimum, average, maximum and standard deviations of individual price factors, such as: materials, labour, equipment, indirect costs, material purchase costs and profit. Three valuations are obtained. On the basis of these values the standard deviation can be calculated. The calculated values are summarised in Table 1.

Table 1: Comparison of minimum, average and maximum price

No	Price-forming factor	minimum value PBC_{min}	average value PBC_{med}	maximum value PBC_{max}
1	M - materials	in line with price indicators 'Cost estimate value of investments' Price indices, eg SEKOCENBUD in Poland or own analysis		
		190 PLN/m²	200 PLN /m²	260 PLN /m²
2	R – labor work	13,54 PLN /wh	15,50 PLN /wh	16,72 PLN /wh
3	S – equipment work	68 PLN/mh	72 PLN/mh	84 PLN/mh
4	Kp(R,S) – indirect cost	62 %	65%	72%
5	Km (M)– cost of material purchase	7%	8%	10%
6	Z(R, S, Kp, Km) - profit	11%	12%	13%

After analyzing the net costs, we have the minimum PBC_{min}, average PBC_{med} and maximum PBC_{max} values. We can calculate the standard deviation σ net costs (2):

$$\sigma = \Big(((PBC_{min} - PBC_{med})^2 + (PBC_{med} - PBC_{med})^2 + (PBC_{max} - PBC_{med})^2)/3\Big)^{1/2} \tag{1}$$

The next step in the calculation is to determine the probability density function for the discount rate and for the price formation factors. It is recommended by ISO 15686-5 to take a normal distribution for the discount rate. With respect to other calculation factors there are no standard recommendations. In scientific studies, different distributions of probability density in relation to price drivers are assumed: [3] triangular, [4] normal and uni, [1] logistical, logarithmic and normal, [5, 7] lognormal, [8] beta. With a large number of data, the correctness of the probability distribution can be tested using the $\chi 2$ test according to [2]. Only 3 minimum, mean and maximum values are taken into account in this calculation method. Therefore, the $\chi 2$ test cannot be carried out. In the article, the beta distribution was assumed for further calculations, as in [8]. Using the proprietary Beta Pert calculation application in EXCEL, the parameters α PBC and β PBC of beta distribution were calculated. Table 2 and equations (3,4,5) show the generalised data formulas.

Table 2: Comparison of generalized data

Lp	Price-forming factor	Symbol	Quantity survey	The unit PBC price
1	Materials	Mi	Y_{mi}	$Mi(normal; Mi_{min}, Mi_{med}, Mi_{max},\sigma_{Mi})$ lub $Mi(beta; Mi_{min}, Mi_{med}, Mi_{max},\sigma_{Mi,}\alpha_{Mi},\beta_{Mi})$
2	Labor work	Ri	Y_{Ri}	$Ri(normal; R_{min}, R_{med}, R_{max},\sigma_{Ri})$ lub $Ri(beta; Ri_{min}, Ri_{med}, Ri_{max},\sigma_{Ri,}\alpha_{Ri},\beta_{Ri})$
3	Equipment work	Si	Y_{Si}	$Si(normal; Si_{min}, Si_{med}, Si_{max},\sigma_{Ri})$ lub $Si(beta;Si_{min}, Si_{med}, Si_{max},\sigma_{Si,}\alpha_{Si},\beta_{Si})$
4	Indirect cost	Kpi=f(Ri,Si)	%	$Kpi(normal, Kp_{min}, Kp_{med}, Kp_{max},\sigma_{Kp})$ lub $Kpi(beta, Kpi_{min}, Kpi_{med}, Kpi_{max},\sigma_{Kp,}\ \alpha_{Kpi},\beta_{Kpi})$
5	Cost of material purchase	Kzi=g(Mi)	%	$Kz((normal; Kz_{min}, Kz_{med}, Kz_{max},\sigma_{Kzi})$ lub $Kzi(beta;Kzi_{min}, Kzi_{med}, Kzi_{max},\sigma_{Kzi,}\ \alpha_{Kzi},\beta_{Kzi})$
6	Profit	Z=h(Ri,Si,Kp)	%	$Zi(normal; Z_{min}, Z_{med}, Z_{max},\sigma_{Zi})$ lub $Zi(beta; Zi_{min}, Zi_{med}, Zi_{max},\sigma_{Zi,}\ \alpha_{Zi},\beta_{Zi})$

Where:

$$\begin{aligned} PBC_n = \sum_{i=1}^{n} (&Mi(normal; Mi_{min}, Mi_{med}, Mi_{max}, \sigma_{Mi}) \\ &+ Ri(normal; R_{min}, R_{med}, R_max, \sigma_{Ri}) \\ &+ Si(normal; Si_{min}, Si_{med}, Si_{max}, \sigma_{Si}) \\ &+ Kpi(normal, Kp_{min}, Kp_{med}, Kp_{max}, \sigma_{Kp}) \\ &+ Kz(normal; Kz_{min}, Kz_{med}, Kz_{max}, \sigma_{KZi}) \\ &+ Zi(normal; Z_{min}, Z_{med}, Z_{max}, \sigma_{Zi})) \end{aligned} \tag{2}$$

or

$$PBC_n = \sum_{i=1}^{n}(Mi(beta; Mi_{min}, Mi_{med}, Mi_{max}, \sigma_{Mi}, \alpha_{Mi}, \beta_{Mi})$$
$$+ Ri(beta; R_{min}, R_{med}, R_{m}ax, \sigma_{Ri}, \alpha_{Ri}, \beta_{Ri})$$
$$+ Si(beta; Si_{min}, Si_{med}, Si_{max}, \sigma_{Si}, \alpha_{Si}, \beta_{Si})$$
$$+ Kpi(beta, Kp_{min}, Kp_{med}, Kp_{max}, \sigma_{Kp}, \alpha_{Kp}, \beta_{Kp})$$
$$+ Kz(btea; Kz_{min}, Kz_{med}, Kz_{max}, \sigma_{KZi}, \alpha_{KZi}, \beta_{Kzi})$$
$$+ Zi(beta; Z_{min}, Z_{med}, Z_{max}, \sigma_{Zi}, \alpha_{Zi}, \beta_{Zi})) \tag{3}$$

or

$$PBC_n = \sum_{i=1}^{n}(Mi(beta; Mi_{min}, Mi_{med}, Mi_{max}, \sigma_{Mi}, \alpha_{Mi}, \beta_{Mi})$$
$$+ Ri(beta; R_{min}, R_{med}, R_{m}ax, \sigma_{Ri}, \alpha_{Ri}, \beta_{Ri})$$
$$+ Si(beta; Si_{min}, Si_{med}, Si_{max}, \sigma_{Si}, \alpha_{Si}, \beta_{Si})$$
$$+ Kpi(normal, Kp_{min}, Kp_{med}, Kp_{max}, \sigma_{Kp})$$
$$+ Kz(normal; Kz_{min}, Kz_{med}, Kz_{max}, \sigma_{KZi})$$
$$+ Zi(normal; Z_{min}, Z_{med}, Z_{max}, \sigma_{Zi})) \tag{4}$$

A calculation analysis is presented below. The calculation was performed using the @Risk add-on to Microsoft Excel, which enables risk analysis by means of Monte Carlo simulation. @RISK shows practically all possible results for each situation and informs about the probability of their occurrence. The calculations were carried out on the assumption that the probability distribution of pricing factors is beta and normal in relation to the inflation coefficient. The results are compared with deterministic calculations, Table 3.

Table 3: The results of calculations for beta distribution and deterministic data for ceramic tile

Name	Min	Mean	Max	5%	95%
beta distribution primary instalation	100,25	118,15	148,52	102,72	139,89
deterministic primary instalation	59,53	74,73	105,88		

All calculations were carried out with reference to the present value PV (6.7.8).

$$PV_{PBC} = \frac{PBC}{(1+r)^m} \tag{5}$$

$$PV_{PBC} = PBC/\,(1 +$$
$$+r\,(betal; r_{min}, r_{med}, r_{max},\ \sigma_r))^{m(betal; m_{min}, m_{med}, m_{max}, \sigma_m\ )} \tag{6}$$

$$PV^m_{PBC} = 1/\,(1 +$$
$$+r\,(normal; r_{min}, r_{med}, r_{max},\ \sigma_r))^{m(normal; m_{min}, m_{med}, m_{max}, \sigma_m\ )}$$
$$+ \sum_{i=1}^{n}(Mi(beta; Mi_{min}, Mi_{med}, Mi_{max}, \sigma_{Mi}, \alpha_{Mi}, \beta_{Mi})$$
$$+ Ri(beta; Ri_{min}, Ri_{med}, Ri_{max}, \sigma_{Ri}, \alpha_{Ri}, \beta_{Ri})$$
$$+ Si(beta; Si_{min}, Si_{med}, Si_{max}, \sigma_{si}, \alpha_{Si}, \beta_{Si})$$
$$+ Kpi(normal; Kp_{min}, Kp_{med}, Kp_{max}, \sigma_{Kp})$$
$$+ Kz(normal; Kz_{min}, Kz_{med}, Kz_{max}, \sigma_{Kzi})$$
$$+ Zi(normal; Z_{min}, Z_{med}, Z_{max}, \sigma_{Zi})) \tag{7}$$

Where:
PV_{PBC} – present value,
PBC – the future amount of money,
r – interest rate (is given as a percentage, but expressed as a decimal in this formula), $r(_{beta}; r_{min}, r_{med}, r_{max},\ \sigma_r)$
m – is the number of compounding years between the present date and the date where the sum is worth PBC, $m(normal; m_{min}, m_{med}, m_{max},\ \sigma_m)$

The cost LCCA of building can be accout (9):

$$PV^{total}_{PBC} = \sum_{m=1}^{100} PV^m_{PBC} \tag{8}$$

Calculations were carried out using the Monte Carlo method in the @Risk Excel program. The results were obtained in a probabilistic form. The results are summarized in Table 5 and presented on Figure 1.

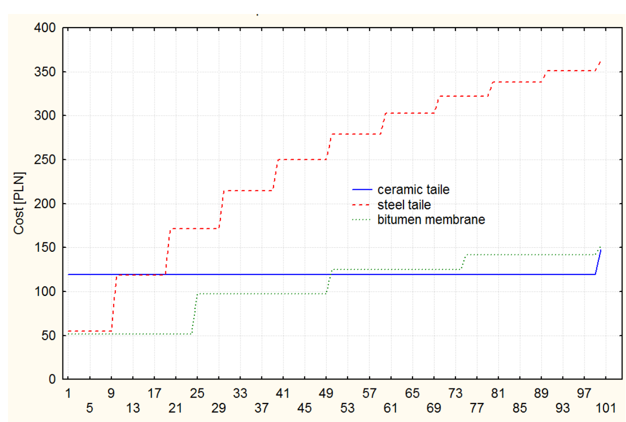

Figure 1: The cost of installing and using roof coverings over a 100-year period

As can be seen in Figure 2, the cost of the original roofing with a steel tile and a bituminous membrane is almost three times lower than that of ceramic roof tiles. When considering PLCCA over 100 years of use (shelf life of 25 years

Table 4: The input data for calculations

Lp	Price-forming factor	Type of material	minimum value PBC_{min} [PLN]	average value PBC_{med} [PLN]	maximum value PBC_{max} [PLN]	standard deviation [PLN]	α_{PBC} Beta	β_{PBC} Beta
primary installation								
1	M –materials*	ceramic tile	39,60	52,52	80,92	17,26	1,25	2,75
		steel tile	22,91	28,99	37,90	5,44	1,60	2,40
		bitumen membrane	25,64	34,56	39,8	5,84	2,52	1,48
2	R - labor	all	13,54	15,5	16,72	1,31	2,47	1,53
		ceramic tile	7,91	9,06	9,77	0,94	2,47	1,53
		steel tile	4,62	5,29	5,70	0,55	2,47	1,53
		bitumen membrane	8,39	9,61	10,37	0,99	2,47	1,53
3	S - equipment work	all	5,50	7,74	10,2	2,35	1,91	2,09
		ceramic tile	0,29	0,41	0,54	0,12	1,91	2,09
		steel tile	0,04	0,53	0,69	0,16	1,91	2,09
		bitumen membrane	0,37	0,53	0,69	0,01	1,91	2,09
4	Kp(R,S) – indirect costs [%]	all	62	65	72	4,19	1,2	2,8
		ceramic tile	5,87	6,16	6,82	4,19	1,2	2,8
		steel tile	3,61	3,78	4,19	4,19	1,2	2,8
		bitumen membrane	6,29	6,59	7,30	4,19	1,2	2,8
5	Km (M)– costs of material purchase [%]	all	7%	8%	10%	1,25	1,35	2,65
		ceramic tile	3,68	4,20	5,25	1,25	1,35	2,65
		steel tile	0,04	0,53	0,69	0,16	1,91	2,09
		bitumen membrane	0,37	0,53	0,69	0,01	1,91	2,09
6	Z(R, S, Kp, Km) – profit[%]	the same	11%	12%	13%	0,82	2	2
		ceramic tile	2,18	2,38	2,58	0,20	2,00	2,00
		steel tile	1,31	1,43	1,55	0,82	2,00	2,00
		bitumen membrane	2,10	3,48	2,48	0,82	2,00	2,00
demolition works								
7	R - labor	R total	13,54	15,5	16,72	1,31	2,47	1,53
		ceramic tile	7,91	9,06	9,77	0,94	2,47	1,53
		steel tile	4,62	5,29	5,7	0,55	2,47	1,53
		bitumen membrane	8,39	9,61	10,37	0,99	2,47	1,53
8	S - equipment work	extract total	5,5	7,74	10,2	2,35	1,91	2,09
		ceramic tile	0,29	0,41	0,54	0,12	1,91	2,09
		steel tile	0,04	0,53	0,69	0,16	1,91	2,09
		bitumen membrane	0,37	0,53	0,69	0,01	1,91	2,09
		truck total	61	75,87	91,93	15,47	1,93	2,07
		ceramic tile	29,89	37,18	45,04	15,47	1,93	2,07
		steel tile	5,49	6,83	8,27	1,39	1,93	2,07
		bitumen membrane	5,79	7,21	8,73	1,47	1,93	2,07
9	Kp(R,S) – indirect costs [%]	the same	7	8	10	1,25	1,35	2,65
		ceramic tile	28,92	30,32	33,59	2,39	1,2	2,8
		steel tile	7,84	8,22	9,11	0,65	1,2	2,8
		bitumen membrane	7,84	8,22	9,11	0,65	1,2	2,8
10	Z(R, S, Kp, Km) – profit[%]	the same	11	12	13	0,82	2	2
		ceramic tile	8,47	9,24	10,01	2,39	2	2
		steel tile	2,30	2,50	2,71	0,65	2	2
		bitumen membrane	2,30	2,50	2,71	0,65	2	2

for a bituminous membrane, 10 years of steel roofing, 100 years of ceramic roof tiles), the cost of a ceramic roof tile is the lowest. Assuming the cost of LCCA bituminos membrane as 100%, the cost of a steel roof tile is 64% and ceramic tile only 26%. The probability of the cost of roof usage in 100 years has been analyzed. The results are presented on Figure 2.

Table 5: The output data of calculation

Name	Material	Min	Mean	Max	probability 5%	probability 95%
primary instalation	ceramic tile	132,33	146,99	170,54	134,58	162,90
in total	ceramic tile	300,08	415,07	579,14	332,78	504,62
primary instalation	steel tile	41,81	42,11	42,65	41,84	42,46
in total	steel tile	101,13	132,84	184,37	105,21	166,49
primary instalation	bitumen membrane	44,16	51,08	60,92	45,09	58,24
in total	bitumen membrane	429,21	569,30	723,70	472,26	681,59

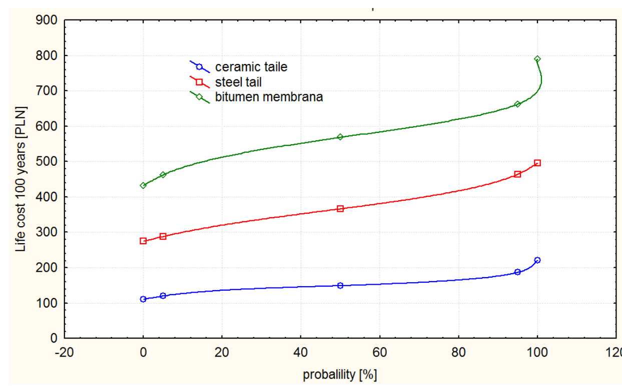

Figure 2: The cost of installing and using roof coverings over a 100-year period as a probability function from 0% to 100%

4 Summary and conclusions

Reilly (2004) indicates that the construction of the line London's Jubilee subway has been delayed by two years, and the cost of implementation exceeded the planned costs by 67% (ie 1.4 billion pounds); tunnel under the channel La Manche exceeded the planned budget by 80%, the bridge over the Great Belt in Denmark is 54% of the overrun costs (Połoński 2010). Such examples can be found in literature more. However, only research carried out under the direction of Flyvbjerg (Flyvbjerg 2002) have been carried out on a large, representative statistical sample of 258 objects. The results of these tests will be unequivocally confirmed - that the problem of underestimating planned investments - is common and affects almost 9 out of 10 respondents investment, with the average analytical overrun - planned costs was 28%. Farr et al. (2016) indicate that simulation-based costing should be replaced by the traditional cost estimate. Advanced analytical tools are needed to incorporate risk and provide more defensible cost estimates. The cost calculation applies not only to the embedding process but also to the cost of use in the life cycle of the building. The article presents a probabilistic method of calculating costs in the lifecycle of a building, on the example of roof coverings. It is very important to take into account costs not only in the first phase of embedding, but also costs of demolition, repairs and replacements. The proposed method is new and has not been used so far.

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