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Material Substitution and Building Life Cycle Costs

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Abstract
Within the scope of the research we are engaged in the effect of new materials mainly made from secondary raw materials on the price of the building structure, the building structure itself, its lifetime and economic efficiency. We are focused on price impact and the whole efficiency of utilization of new materials developed within the scope of related research. The production of these materials may not be always economically profitable, but their utilization can have a great ecological importance. The main objective of this paper is to present the way in which to simulate the effect of building material substitution on the prices of building constructions and of the building life cycle efficiency on the model situation through the utilization of mathematical methods.

Keywords
Secondary Raw Materials, Economic Lifetime, Economic Efficiency

1. Introduction

This contribution deals with the issue of substituting selected building materials made from traditional natural raw products with materials made from recycled raw products, and the resulting effect on the total cost of building and on the economic efficiency of the building's life cycle. The first part of the contribution deals with the effect of material substitution on the resulting building project price, and the second part assesses the impact of the substitution on other costs occurring during the whole life cycle of the building.

2. Effect of material substitution on the resulting building project price

2.1 Model characteristics

The effect of building material substitution on the building object price can be simulated in the case study. Representative energy saving building for living was chosen for the case study. Within the scope of the case study we monitor substitutions of building materials made from natural raw materials by materials made from secondary raw materials.
The case study is designed with the help of Crystal Ball software, which uses the Monte Carlo method for the simulation of calculations within the defined model. In our case the model is defined as the lifecycle of a building. In the calculation of the building lifecycle costs the Crystal Ball software is used for taking into account uncertainties of inputs entering the lifecycle costs calculation and for projection of these uncertainties into the final result in the form of total building lifecycle costs.

In the first phase we focused on the simulation of the effect of material substitution on the costs connected with acquisition of the building. The definition of the model and actual simulation took place using the following steps:

- Within the frame of the building, materials were defined that will in the future be substituted by materials made from secondary raw materials.
- Based on historical data, average unit prices of materials made from natural raw materials were founded and probability distributions were defined for these prices with the help of the Crystal ball software. In the case of materials from secondary raw materials, individual calculations were carried out and probability distribution was suggested based on experiences with natural materials.
- Price calculation of the building assessment
- Definition of two versions for the price calculation of the building simulation:
    - Version A: only materials made from natural resources were used in the price calculation.
    - Version B: in the price calculation concrete C 16/20 made from natural resources was substituted by concrete made using secondary raw materials.
- Simulation of the dependence of the building price on prices of selected materials, defined with the help of the specific rate of uncertainty for versions A and B, based on the Monte Carlo method.
- Comparison of particular versions.

2.2 Results of calculation

The results of simulation during which the material made of natural raw products was substituted with material made from recycled raw products are apparent from the following figures and table. The figures depict the course of simulation by the Monte-Carlo method with software assistance from the Crystal Ball program, and therefore also the effect of substitution on the building price. Other more detailed statistical characteristics are shown in the table below them.

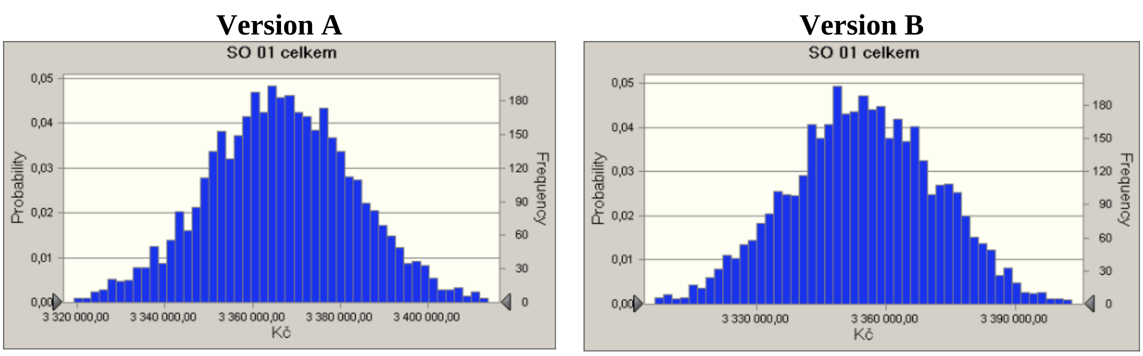

Figure 1: Results of simulation and comparison of Version A and Version B

Table 1: Results of simulation

Statistics (Total Price of Building)	Forecast values			
	Version A		Version B	
	CZK	€	CZK	€
Number of trials	4 000	4 000	4 000	4 000
Mean	3 366 465	118 340	3 354 736	117 938
Median	3 366 319	118 345	3 354 538	117 931
Standard Deviation	16 877	593	17 283	608
Minimum	3 304 640	116 176	3 291 553	115 716
Maximum	3 423 166	120 343	3 417 528	120 145
Range Width	118 526	4 167	125 975	4 429

Simulation of the substitution of the concrete made from natural raw materials by the concrete made from secondary raw materials has in this case an insignificant effect on the building price.

3. Defining criteria for measuring investment efficiency with regard to material substitutions

To determine the economic efficiency related to constructing and operating the buildings, all the costs of operation and elimination stages must be considered as well as the initial acquisition (investment) costs.

The basic formula for determining the building's life cycle costs is shown below:

$$LCC = C_T + C_P + C_A$$

where

LCC… life cycle costs
C_T … costs pertaining to technical parameters of the building
C_P … operating costs
C_A … administration costs

3.1. Cost characteristics during the life cycle

Individual costs occur during the whole life cycle of the building and so it is necessary to account for the time factor by transforming the defined costs to their current value, setting a proper discount rate when computing each cost item.
The value of total costs of the building's life cycle can be determined with the following formulas, which take temporal values of money flows into consideration:

Costs pertaining to the building's technical parameters (C_T)

$$C_T = \sum_{i=0}^{n} \frac{\sum_{j=1}^{t} C_{Tj}}{(1+r)^i}$$

where

C_{Tj} value of costs of j-th category pertaining to the building's technical parameters in i-th year of evaluation
n length of the building's life cycle
t total number of categories of costs pertaining to the building's technical parameters
r discount rate

Operating costs (C_P)

$$C_P = \sum_{i=0}^{n} \frac{\sum_{j=1}^{t} C_{Pj}}{(1+r)^i}$$

where

C_{Pj} value of operating costs of j-th category in i-th year of evaluation
n length of the building's life cycle
t total number of categories of operating costs
r discount rate

Administration costs (C_A)

$$C_A = \sum_{i=0}^{n} \frac{\sum_{j=1}^{t} C_{Aj}}{(1+r)^i}$$

where

C_{Aj} value of administration costs of j-th category in i-th year of evaluation
n length of the building's life cycle
t total number of categories of administration costs
r discount rate

3.2. Determination of the total building life cycle costs

The previous chapter describes the costs that can occur in terms of acquisition, operation and elimination of the buildings. However, the list of costs is not final and it will be supplemented during further research.

Investment efficiency is the fundamental criterion of material substitution impact assessment. For materials made of secondary raw products, it is a tool for deciding about the economics of their use in construction. The net impact of material substitution on investment efficiency can be assessed by means of the effect of this substitution on the building's life cycle costs. These costs can be clearly presented and subsequently determined using the following table:

Table 2: Building life cycle costs

The building's life cycle stages	Investment costs			Operating costs			Elimination costs		
Year	**1**	**2**	**…m**	**1**	**2**	**…n**	**1**	**2**	**…o**
Building acquisition costs	**0**	**0**	**0**						
- …	0	0	0						
- …	0	0	0						
- …	0	0	0						
Maintenance costs				**0**	**0**	**0**			
- …				0	0	0			
- …				0	0	0			
- …				0	0	0			
Repair costs				**0**	**0**	**0**			
- …				0	0	0			
- …				0	0	0			
- …				0	0	0			
Reconstruction costs				**0**	**0**	**0**			
- …				0	0	0			
- …				0	0	0			
- …				0	0	0			
Renovation costs				**0**	**0**	**0**			
- …				0	0	0			
- …				0	0	0			
- …				0	0	0			
Building elimination costs							**0**	**0**	**0**
- …							0	0	0
- …							0	0	0
- …							0	0	0
Year of building	***1***	***2***	***3***	***4***	***5***	***...n***	***n+1***	***n+2***	***...o***
Total LCC	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Total LCC – discount	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Total LCC – discount, accumulated	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

The resulting outcome of the table is a sum of the total discounted building life cycle costs. If material substitution brings about a decrease in this value, then it is advisable from an economic point of view to carry out the substitution and to use the new material for realization of the building project. The table indicates that only costs pertaining to the building's technical parameters (C_T) were taken into account for determination of the impact of material substitution on the building's life cycle costs; operating costs and administration costs are not relevant for the calculation.

4. Conclusion

The construction needs efficient materials. Efficient material is demanded by the investor and also by society as a whole. The relation of the material to the efficiency is monitored in case studies. We are mainly interested in new materials described in partial sections of the common research and the possibility of using these materials in practice.

The relation of the material to the efficiency is monitored in the case study of the building for living in. In this phase of the research the structure of the prepared model was suggested. We are working in the testing phase. Partial results of calculations offer information about costs for the building acquisition at the material substitution. In the case study a substitution of concrete C 16/20 was realized. Values are calculated using the Monte Carlo method with a specific probability.

5. Acknowledgment

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