Maintenance and operation costs model for university buildings

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ISSN 1330-3651 (Print), ISSN 1848-6339 (Online)
DOI: 10.17559/TV-20140606093626

MAINTENANCE AND OPERATION COSTS MODEL FOR UNIVERSITY BUILDINGS

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Preliminary communication
Costs of maintenance and operation are important part of the Life cycle costs. This paper describes development and validation of a new model for predicting average annual costs of maintenance and operations for the University buildings in Osijek with similar building characteristics. The model is developed based on historical cost data records obtained from 13 University buildings in Osijek for time period of 12 years starting from 1998. The model was tested at two new sets of data, in buildings outside of Osijek. The proposed operating and maintenance costs model requires reduced amount of data for predicting annual maintenance and operations costs of University buildings of similar building characteristics and highlights statistically significant data required for costs prediction. The model contains only few elements but yet can predict operating and maintenance costs. The proposed model enables maintenance and operations cost estimates already at the initial design phase.

Keywords: *cost analysis; life cycle costs; maintenance; mathematical modelling; predictions*

Model procjene troškova održavanja i uporabe sveučilišnih građevina

Prethodno priopćenje
Troškovi održavanja i uporabe su neizostavan dio troškova životnog ciklusa. U radu se opisuje razvoj i validacija novog modela predviđanja prosječnih godišnjih troškova održavanja i uporabe sveučilišnih građevina sličnih karakteristika u Osijeku. Model je razvijen prema stvarnim troškovima održavanja i uporabe 13 građevina Sveučilišta u Osijeku koji su prikupljeni za vremensko razdoblje od 12 godina počevši od 1998. godine. Model je ispitan na dvije građevine slične namjene izvan Osijeka. Primjenom predloženog modela predviđanja troškova održavanja i uporabe uz malu količinu ulaznih podataka moguće je predvidjeti godišnje troškove održavanja i uporabe građevina slične namjene te omogućiti uvid u statistički značajne varijable potrebne za predviđanje spomenutih troškova. Predloženi model omogućuje procjenu troškova održavanja i uporabe već u fazi planiranja projekta.

Ključne riječi: *analiza troškova; matematičko modeliranje; održavanje; predviđanje; troškovi životnog ciklusa*

1 Introduction

Usually all participants in construction devote attention primarily to reduction of construction costs. Participants are seldom devoted and pay any attention to reduction of maintenance and operations cost of facilities and as even more important to cutting down the life cycle costs of new and existing facilities [1]. Some participants in construction (for example architects and designers) have at their disposal a large number of different models and methods for assessment and scheduling of construction costs, but on the other hand there is a limited number of models and methods for planning future costs of facilities during the usage phase [2]. Life cycle costs are the total costs of a building or its parts throughout its life, including the costs of planning, design, acquisition, operations, maintenance and disposal, less any residual value [3]. LCC perspective has proved to be most meaningful during the design phase where the possibilities of cutting down the costs related to operation and maintenance are large [4]. One potential use of LCC analysis is its use as a predictor of facility cost performance [5]. It has been reported that most of the LCC of a product are committed during the design stage [6].

Research conducted in the USA provided the following information:

- Yearly costs of maintaining individual facilities may exceed the initial cost of construction by 10 %;
- Since 2003 operations costs of non-residential facilities have increased more than 25 %;
- Annual costs increased by an average 4,5 % [7];

Maintenance can be defined as a work necessary to maintain the original anticipated useful life of fixed asset [8]. Facilities operations account for 50 % to 75 % of the facilities budget [8]. In developed economies, approximately 50 % of financing in construction is accounted for operating and maintenance costs and those costs per annum may amount to 3 % of the initial capital cost of the building, for example nearly 50 % of all construction output in the UK during 1997 was spent on repair and maintenance [9]. From total construction related investments in Sweden in year 2002 approximately 37 % were costs of maintenance and repair [10]. Maintenance and operations costs of University facilities and other public facilities with similar function in Croatia are mostly covered by public finance. It is therefore extremely essential to plan and manage the above mentioned costs and to take into consideration some peculiarities of public buildings [11]:

- Low or zero real discount rates, reflecting the particular nature of public works projects as social rather than investment capital;
- "Cradle to grave" (life cycle) or long periods of analysis;
- Low or zero income/revenue flows;
- Selection of systems and components based principally on their longevity/durability;
- Sustainability performance (with a particular emphasis on environmental and societal impacts).

In order to analyse and predict maintenance and operations costs of buildings at the University of Osijek or buildings of similar building characteristics and purposes it is necessary to develop predictive models of these costs which are not possible without forming a suitable database of independent and dependent variables that can be statistically processed. There are several cost categories that should be taken into account when budgeting LCC, those costs are costs of acquisition, maintenance, operation, management, disposal and demolition, and eventually residual value of the facility at the end of its life [12]. According to ISO 15686:5-2008 WLC consists of non-construction-costs, incomes and LCC (Fig. 1) [13]. This cost structure was also applied in this paper. Maintenance and operations costs are costs of statutory periodic inspections, costs of replacing degraded materials and elements, costs of periodic works and repairs, costs of reactive maintenance and operating costs [1]. There are various data requirements for carrying out LCC analysis (Fig. 2) and these different types of data influence the LCC in different stages of the life cycle [14]. Required data should be collected and processed in an appropriate way to facilitate the implementation of the LCC analysis. Throughout the years numerous life cycle cost models have been generated. But none of those models has been commonly accepted. There are a great deal of reasons for not having a commonly accepted model, including the users preference, the presence of various systems of cost data gathering, and many different types of equipment, appliance, or systems [15]. There are two basic flaws of existing LCC models and models for predicting maintenance and operations costs: low prediction accuracy of costs and restrictions associated with different stages of buildings life cycle [16]. Various models comprise different types of costs depending on the accepted cost structure where we distinguish two types of models. First type of cost models are those where maintenance and operations costs cannot be derived, and second type of cost models are those where maintenance and operations costs are easily derived.

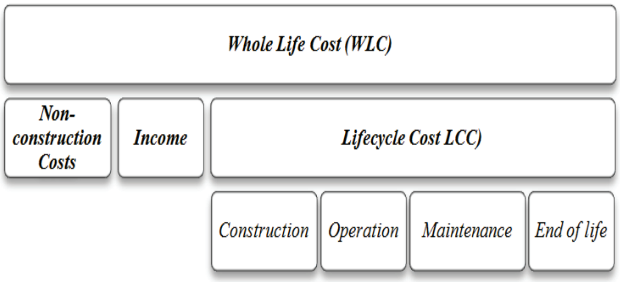

Figure 1 Whole Life Cost and Life Cycle Cost Elements [13]

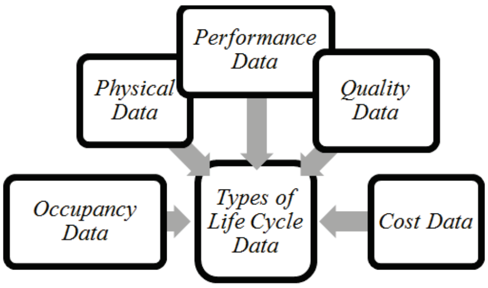

Figure 2 The required data categories for a LCC analysis [14]

Analysis of LCC method and existing maintenance and operations cost models revealed the following:

- Maintenance and operations costs represent most important part of buildings life cycle costs;
- Current models mostly are not based on historical cost documents;
- Models that are based on historical cost documents are mainly developed based on available cost structure, and not on predetermined cost structure;
- There are no adequate databases containing evidence about maintenance and operations costs that could be used for future research to update or improve existing models of the University buildings in the eastern European countries;
- There is no groundwork for data classification;
- There is no simple model for predicting maintenance and operations costs based on building attributes, operational arrangement and user characteristics;
- Model developed by Flanagan et al. in 1989 [17] is a computational complex, and besides that, it does not have the possibility to determine the share of individual groups of costs in the total life cycle costs;
- Model developed by Sobanjo in 1999 [18] assumes that all maintenance and operation costs occur annually;
- Model developed by Kirkham in 2002 [19] is applicable only to hospital buildings, second model they developed is used only for sports facilities [20];
- Model developed by Adeli & Sarma in 2006 [21] is used only for steel construction.

Considering all stated above and the fact that there are no models that can be used for predicting maintenance and operation costs of university buildings this paper explores the possibility of creating the new maintenance and operation cost model based on historical cost records of university buildings.

2 Objectives

Research presented in this paper is exploring the possibility of gathering information related to building characteristics and occupational characteristics of facilities at the University of Josip Juraj Strossmayer in Osijek. Further on it explores the possibility of gathering data related to maintenance and operation costs. Research presented in this paper was conducted by utilizing information gathered from buildings at the University of Osijek. There are no reliable data about buildings construction cost - most of them are older than 60 years and majority of them are part of architectural heritage (some of them were built during 19 century) so their removal or demolition is not a valid option. Considering stated above the research is focused on exploring the possibility of predicting and optimizing operation and maintenance costs as an integral and important part of LCC.

Buildings at the University of Osijek are unique for several reasons:

- They are located across the town of Osijek;
- Most of the buildings were built before 1950s;
- They are considered as public buildings whose maintenance and operations costs are financed from the public budget;
- There is a specific operational scenario, which is characterized by waste amount of users during the year, but there is also an extremely small number of users during a brief period of year (summer break);

This research provides the following information:

- Possibility of collecting historical data on maintenance and operations costs of buildings at the University of Osijek;
- Data about actual historical maintenance and operations costs of these buildings;
- Development of maintenance and operations costs database;

- Identification of significant groups of costs in overall maintenance and operations costs of buildings at the University of Osijek;
- Definition of statistically significant independent variables required for defining mathematical model that could be utilised for prediction of maintenance and operations costs of buildings at the University of Osijek.

3 Methodology

Information necessary for this survey was collected by using a questionnaire sent to all institutions at the University. Data regarding general building characteristics and operational - usage characteristics, considering occupants were requested. Information about maintenance and operations costs were gathered by using predetermined cost data structure. Analysis of collected data enabled the formation of data base containing maintenance and operations costs based on historical data records. Historical records have already been used in some studies in order to predict and plan building characteristics or certain types of costs [22]. Data were collected for time period of 12 years starting from year 1998. The reason for choosing this time period rather than a longer one was avoidance of costs incurred related to war destruction in Croatia during period from 1991 to 1995.

The questionnaire was sent to constituents of the University and consisted of four parts:

Part 1: General building characteristics (Data regarding building's age, time period in which the building has been used for University purposes, overall surface area, etc.)

Part 2: Facility maintenance data (Data regarding buildings facility maintenance, facility manager that is responsible for the facility maintenance activities, existence of a maintenance strategy, number of users in the future, etc.)

Part 3: Building operational characteristics (Data regarding buildings regions and their corresponding areas, total area of buildings, number of shifts, number of users, number of staff and students, etc.)

Part 4: Maintenance and operations costs were classified in five groups, for each group various costs categories were proposed, but there was the possibility to enter new cost categories if missing/needed in existing cost categories. Data were collected for Statutory periodic inspections costs, Life cycle replacement costs, Costs of periodic works and repairs, Costs of reactive maintenance and Operation costs. After collecting data the following problems occurred: in some buildings activities are performed by two faculties, some faculties have buildings outside of Osijek and the third problem were the faculties whose activities take place in several buildings across the town. Since the target of this research were complete buildings, the first problem was solved by adding up data regarding costs and average number of users of both faculties, because information about functional surface area is the same for both faculties and in further research those buildings were treated as one facility. Second problem was solved by declining cost data of buildings outside of Osijek. And finally the third problem was solved because accounting offices were able to provide separated costs depending on faculties locations.

In conformity with collected data total nominal annual maintenance and operation costs were calculated. In order to determine average nominal annual maintenance and operation costs of the University buildings those total nominal costs were divided by time period for which data were obtained (reference period). The same procedure was applied in order to get average number of users i.e. students and staff. Other independent variables did not change during the observed time period e.g. number of shifts, buildings surfaces areas, storeys number etc. Among constituents that delivered requested data (13 constituents, 87 % of all constituents of the University) there were also data that were fragmentary, i.e. cost records were not given at all or they were specified only for some of the requested cost categories. Part of constituents delivered only data regarding operational characteristics and operational policy. According to these data it was resolved which buildings can be used in forming the database. Essential requirement to be satisfied in order to consider data sufficiency for entering database was completeness of data in questionnaires what at the end lead to the fact that 76,92 % of all obtained questionnaires were accepted. Number of years for which requested data were obtained ranged from 4÷12 years (Fig. 3), this information about time period for which data were obtained was called the reference period.

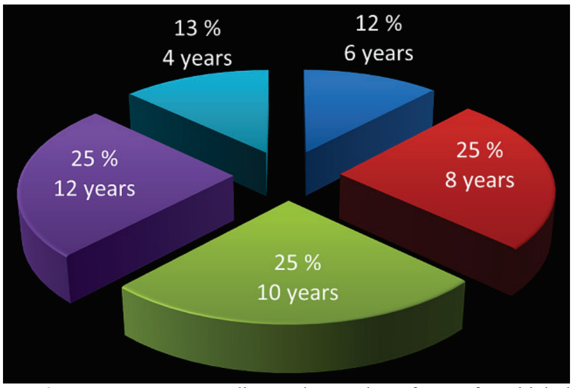

Figure 3 Data structure according to the number of years for which data were gathered

Independent variables list was established based on literature review and previous research of related subject. Selected independent variables can be considered relevant for defining independent variables and they represent potential variables of buildings maintenance and operation costs predicting models. Dependent and independent variables database was established based on statistical analysis in order to obtain descriptive statistics information and basic statistical parameters of dependent and independent variables (Tab. 1). All costs are in kunas, 1€ = 7,53 kn on June 27. 2012 [23]. Formed database in Tab. 1 was applied for statistical processing and application of regression analysis. The null hypothesis is that the model for predicting maintenance and operations costs will have no explanatory power.

Reasons to apply regression models were [24]:

1) Descriptive - form the strength of the association between outcome and factors of interest,
2) Adjustment - for covariates/cofounders,
3) Predictors - to determine important risk factors affecting the outcome,
4) Prediction - to quantify new cases.

Table 1 Descriptive statistics and list of dependent and potential independent variables appropriate for defining model for prediction of maintenance and operations costs of the University buildings

Independent variables	Mean	Median	Minimum	Maximum	Variance	Std. Dev.	Coef. Var.	Standard Error	Skewness	Variable mark
Building age	123,00	109,00	10,00	293,00	9498,86	97,46	79,24	34,46	0,92	var1
Time period used for University purposes	14,13	11,50	4,00	33,00	88,70	9,42	66,68	3,33	1,36	var2
Reference period	8,75	9,00	4,00	12,00	7,93	2,82	32,18	1,00	-0,48	var3
Number of storeys	4,00	4,00	3,00	5,00	0,86	0,93	23,15	0,33	0,00	var4
Classroom area	846,67	959,47	284,42	1100,00	79074,22	281,20	33,21	99,42	-1,49	var5
Teachers cabinets area	735,09	747,00	223,20	1169,59	85232,62	291,95	39,72	103,22	-0,32	var6
Hallways area	966,29	788,50	140,00	2192,76	464407,67	681,47	70,53	240,94	0,89	var7
Sanitary area	222,17	160,00	72,33	680,00	38945,54	197,35	88,83	69,77	2,20	var8
Office area	337,08	320,77	139,75	755,00	36881,70	192,05	56,97	67,90	1,61	var9
Library area	85,87	95,87	0,00	143,65	2071,83	45,52	53,01	16,09	-0,93	var10
Laboratory area	471,80	448,00	0,00	1560,00	244964,51	494,94	104,90	174,99	1,67	var11
Other areas	585,32	446,50	100,00	1322,72	197803,05	444,75	75,98	157,24	0,72	var12
Overall surface area	4315,25	4227,00	2375,00	7345,00	2194716,21	1481,46	34,33	523,77	1,09	var13
Avg. number of staff	90,38	73,00	38,00	178,00	2918,27	54,02	59,77	19,10	1,09	var14
Avg. number of students	788,38	583,00	189,00	2540,00	547855,13	740,17	93,89	261,69	2,35	var15
Number of shifts	1,88	2,00	1,00	2,00	0,13	0,35	18,86	0,13	-2,83	var16
Dependent variable	Mean	Median	Minimum	Maximum	Variance	Std. Dev.	Coef. Var.	Standard Error	Skewness	Variable mark
Maintenance and operations costs	1,12E+06	8,21E+05	5,86E+05	2,18E+06	4,03E+11	6,35E+05	56,89	2,24E+05	1,03	var16

In many problems there are two or more variables that are related, and it is of interest to model and explore this relationship, the relationship between these variables is characterized by mathematical model called a regression model [25]. Regression analysis goal is creation of mathematical model that can be used to predict the values of a dependent variable based on values of one or more independent variable [26]. Some problems arrived when regression analysis was applied at the defined database:

- The choice of only relevant variables among all possible independent variables;
- Such choice of variables frequently causes appearance of correlation between variables, and may lead to a greater number of selected variables than sample size.

Problem of variable selection is a known problem of regression analysis because selected model should contain only the important variables and no more, with minimal prediction error [27]. Therefore, if it is unknown which variables are not needed, any set of variables must be based on gathered data. In other words, variables are chosen or deleted based on statistics such as p-values (statistical significance) of coefficients estimated by the data being analysed [28]. In this research multiple regression analysis and *Stepwise* procedure were applied in order to determine significant variables of models. The success of this method is highly dependent on p-values for deciding on addition and elimination of variables [28]. For this purposes software SAS8.1® was applied.

The value of the p-value represents a decreasing index of the reliability of a result, the higher the p-value, the less we can believe that the observed relation between variables in the sample is a reliable indicator of the relation between the respective variables in the population [29]. The value of the p-value in this research was 0,05 and it indicates that there is a 5 % probability that the relation between the variables found in sample is accidental. The p-value of 0,05 is customarily treated as a "border-line acceptable" error level [29]. Statistical significance is defined at level of 5 % and indicates probability that some other measurement will yield difference between new measurement and sample that is slight, less than 5 % [30]. Random sampling from identical population would give difference at the same level or less than 95 % of cases and bigger difference would be expected in only 5 % of population.

Results that yield $p \leq 0,05$ are considered borderline statistically significant, results that are significant at the $p \leq 0,01$ level are commonly considered statistically significant, and $p \leq 0,005$ or $p \leq 0,001$ levels are often called "highly" significant [29]. But it is important to keep in mind that these classifications represent nothing else but arbitrary conventions that are only informally based on general research experience [29].

In testing hypotheses it is easy to be confused by the distinction between statistical significance and practical importance, a statistically significant result may be of little practical importance [31]. Due to this fact for further analysis variables with $p \leq 0,08$ were also considered. Since it is found that statistically significant variables exist the null hypotheses that model has no explanatory power now can be rejected (Tab. 2).

Table 2 Statistically significant variables for prediction model

Variable	Description	*p*-value
var7	Hallways area	0,0130
var9	Office area	0,0627
var13	Overall surface area of building	0,0725

Performed *Stepwise* procedure granted analysis of various potential models for calculating and predicting maintenance and operations costs of the University buildings (Tab. 3). Proposed models are given together with their related coefficient of determination (R^2), adjusted coefficient of determination (R_{adj}^2) and related independent variables. Given the relatively small sample size, although all University buildings were included in this research, for further considerations were taken only models with a maximum of 3 variables (Tab. 3).

Table 3 Maintenance and operations costs prediction model variables

R-Square	Adjusted *R*-Square	Variable Mark	Variables in Model		
0,6697	0,6147	var7	Hallways area		
0,4648	0,3756	var9	Office area		
0,4410	0,3478	var13	Overall surface area		
R-Square	Adjusted *R*-Square	Variable Mark	Variables in Model		
0,8444	0,7821	var7 var15	Hallways area	Avg. number of students	
0,7046	0,5865	var1 var7	Building age	Hallways area	
0,7006	0,5808	var4 var7	Number of storeys'	Hallways area	
R-Square	Adjusted *R*-Square	Variable Mark	Variables in Model		
0,8951	0,8164	var1 var7 var15	Building age	Hallways area	Avg. number of students

As a model selection criterion some of the above mentioned values could be applied but it is important to keep in mind that R^2 cannot decrease as independent variables are added to the model and the model that gives maximum R^2 will necessarily be the model that contains all independent variables [27, 32]. Thereby instead of applying R^2 it is advisable to apply R_{adj}^2 which does not always increase as variables are added to the model and attempts to estimate what the prediction error would be on new data [32, 33]. No subset model will have an R_{adj}^2 larger than that of the full model, which includes all predictor variables, but there may exist subset models with R_{adj}^2 values that are nearly equal to that of the full model [34]. Values applied as model selection criterion are listed below and presented in table 4 together with related independent variables Predicted residual sums of squares (PRESS), Root mean square error of cross validation (RMESCV), R^2 & R_{adj}^2.

Table 4 Maintenance and operations costs prediction models with related model selection values

Maintenance and operations cost prediction models	PRESS	RMSECV	R^2	R_{adj}^2
M1 (var7)	1,4875E+12	431205	0,6697	0,6147
M2 (var9)	2,2243E+12	527293	0,4647	0,3756
M3 (var13)	2,1269E+12	515613	0,441	0,3478
M4 (var7 & var15)	3,0013E+12	612506	0,8444	0,7821
M5 (var1 & var7)	1,5342E+12	437926	0,7046	0,5865
M6 (var4 & var7)	1,8033E+12	474779	0,7006	0,5808
M7 (var1 & var7 & var15)	2,5024E+12	559290	0,8951	0,8164

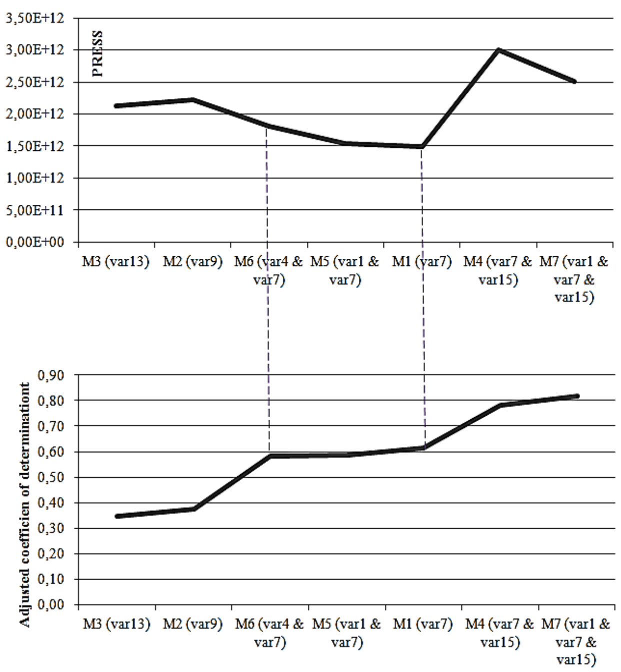

Figure 4 Maintenance and operations cost models with related variables, adjusted coefficient of determination and predicted residual sums of squares

PRESS is calculated via a leave one out cross validation where each sample is left out of the model formulation and predicted once [35].

Values from table above can be sorted ascending according to R_{adj}^2 from smallest to largest and then present graphically in order to observe range of optimal predicted residual sums of squares values (Fig. 4). It should be also noted that R_{adj}^2 tends to stabilize around some upper limit as variables are added and the simplest model with R_{adj}^2 near this upper limit can be chosen as the "best" model [32].

Since PRESS is used to RMSECV that represents measure of a model's ability to predict results on new samples and stable R_{adj}^2 values the next three maintenance and operations costs models will possibly have the greatest prediction power among others and need further considerations: M1 (var7), M6 (var4 & var7) & M5 (var1 & var7).

4 Results

Based on the conclusions from previous chapter and results of stepwise regression analysis three maintenance and operations cost models were developed with related regression coefficients. By applying those models it is possible to calculate average annual nominal maintenance and operations costs (*MOC*) of the University facilities expressed in Croatian national currency or in Euros. First model uses only one independent variable for cost predictions, Hallways area (A_H) expressed in m^2:

$$MOC_1 = 379184 + 762{,}09 \cdot A_H \ \text{(kn)} \quad (1)$$

$$MOC_1 = 50356{,}44 + 101{,}21 \cdot A_H \ (€) \quad (2)$$

Second model uses two independent variables for cost predictions:

$$MOC_2 = 1005069 - 135840 \cdot S + 676{,}68 \cdot A_{\mathrm{H}} \text{ (kn)} \quad (3)$$

$$MOC_2 = 133475{,}30 - 18039{,}84 \cdot S + 89{,}86 \cdot A_{\mathrm{H}} \text{ (€)} \quad (4)$$

where S stands for number of buildings storeys and A_{H} is an overall hallways area of building expressed in m^2.

Third model applies also two independent variables for cost predictions:

$$MOC_3 = 441527 - 1508{,}05 \cdot B_{\mathrm{a}} + 889{,}54 \cdot A_{\mathrm{H}} \text{ (kn)} \quad (5)$$

$$MOC_3 = 58635{,}72 - 200{,}27 \cdot B_{\mathrm{a}} + 118{,}13 \cdot A_{\mathrm{H}} \text{ (€)} \quad (6)$$

where B_{a} stands for building age and A_{H} is an overall hallways area of building expressed in m^2.

One must also consider how well the model predicts response values that were not applied in development of the candidate models (test data). In order to avoid over-fitting, an independent test set is preferred. In this paper one out validation was applied. The downside is that this procedure does not use all the available data and the results are highly dependent on the choice for the training/test split [36]. For validating purposes presented models are tested on test data, i.e. buildings outside the city of Osijek. When applying models on test data it is important that new variables range is within the limits of variables range used for defining regression coefficients (training set). Otherwise it is possible to get completely inaccurate results of prediction [25]. First step that needs to be taken before applying models on test data is to check if variables of test data set are within the limits of training data variables (Fig. 5).

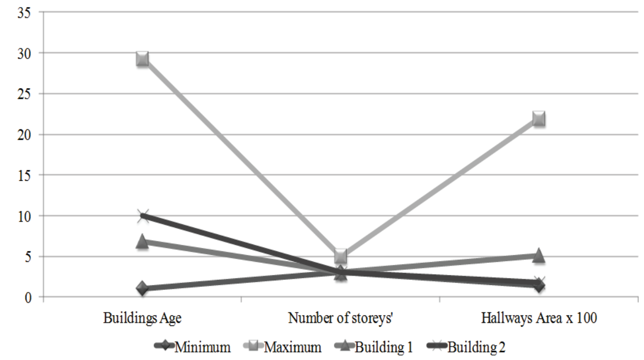

Figure 5 Range of variables used for defining regression coefficients of proposed models and range of variables of test data

Since new variables range is within the limits of variables range used for defining regression coefficients of proposed models (Fig. 5) it is possible to test models on test data. The accuracy (A_{C}) of the cost calculated using the model is the percentage difference between the cost predicted by the model and the actual costs. The closer the value of A_{C} is to zero the more accurate is the model and it can be calculated according to the following expression [37]:

$$A_{\mathrm{C}} = \left[\frac{PC - AC}{AC} \right] \cdot 100\,\% \quad (7)$$

The mean model accuracy ($\overline{A}_{\mathrm{C}}$) for a series of tests is the arithmetic average of A_C and can be calculated as:

$$\overline{A}_{\mathrm{C}} = \frac{\sum_{i=1}^{n} A_{\mathrm{C}}}{n} \quad (8)$$

where n is the number of data sets. Zero mean model accuracy indicates that the model does not, on average, under or overestimate the actual costs [37]. The precision of the model is determined by the scatter of the individual accuracies for a series of buildings in one category. This dispersion is represented by the standard deviation (std) of A_{C}.

The total accuracy (A_{m}) of the model is [37]:

$$A_{\mathrm{m}} = \overline{A}_{\mathrm{C}} - std \text{ of } A_{\mathrm{C}} \quad (9)$$

A_{C} and A_{m} of the models were calculated for test data set and training data (Tab. 5).

Based on the above presented the first model (expression 1 or 2, depending on currency) with one independent variable for cost predictions (hallways area, var7) is selected as a final model for predicting maintenance and operations costs for several reasons:

- Minimum values of A_{m} for training data sat (Tab. 5);
- Reasonable values of R_{adj}^2 and the lowest value of PRESS of all proposed models (Fig. 4);
- Variable 7, Hallways area, is significant due to the fact that is expected to be present in all buildings for which the maintenance and operations costs could be predicted with proposed model;

Application of the proposed model for predicting maintenance and operations building costs has several advantages over the existing models:

- The first and greatest advantage of applying the proposed model is simplicity, since the model requires a single variable for cost prediction;
- Information about overall Hallways area is possible to be obtained at an early design stage of the project and therefore already at this stage, the proposed model enables the assessment of maintenance and operations costs of different building design solutions;
- Alteration of this variable provides various design solutions evaluating from the maintenance and operations costs optimization perspective;
- By applying the proposed model it is possible to predict an average annual maintenance and operations buildings cost which allows easier comparison and prediction of those costs on an annual or semi-annual level at university level.

The main model limitations are also defined:

- For the time being primary main limitation of the model is applicability only to buildings at the University of Osijek. Although applicability was tested at two buildings outside of the city of Osijek and one of them has different purpose it is necessary to test the model on more buildings with the same or similar purpose in Osijek and outside of Osijek in order to prove its applicability.
- When applying the model, it is important that variable hallways area is within the range of variables

range used for defining regression coefficients. First step that needs to be taken before applying the model is to check if the variable of new building is within the limits of the variables used in development of the candidate model.

Table 5 Maintenance and operations cost models validation results on test data and training data

Models		MOC_1 (var7) (%)	MOC_2 (var1 & var7) (%)	MOC_3 (var4 & var7) (%)
Training Data Set	$\overline{A}_C$	9,90	9,48	8,45
	Std. Deviation of A_C	39,30	39,76	40,74
	A_m	−29,40	−30,27	−32,29
Test Data Set	$\overline{A}_C$	8,24	42,46	17,74
	Std. Deviation of A_C	11,02	26,98	19,91
	A_m	−2,78	15,48	−2,17

5 Conclusion

Even though methods and principles of LCC have been known for many years now, the method is still not widely accepted among all participant of construction, especially during the design phase. Possible reason for this lies in the fact that reliability is often questionable and there is a lack of motivation due to the complexity of the method. The research presented in the paper was aimed at analysing the maintenance and operation costs of buildings with similar characteristics at the University in Osijek. Data were collected using a questionnaire sent to all constituents of the University, general data about the facilities operation and characteristics and data concerning costs of maintenance and operation were requested according to pre-defined cost data structure.

The research found that it is possible to collect necessary data with applied method and the result of research was the creation of database with dependent variables, maintenance and operations costs, and independent variables, building characteristics and operational characteristics that are statistically significant for predicting maintenance and operations costs. The research found that it is possible to create mathematical models for predicting maintenance and operations costs of public buildings at the University by applying the proposed statistical methods. It was found that it is possible to apply multiple regression analysis to develop models for predicting maintenance and operations costs and to use Stepwise method to determine statistically significant variables of the cost models. By applying the model developed in this research it is possible to plan and calculate the maintenance and operational costs of the University buildings for certain time periods.

Presented research analysed which factors can affect maintenance and operations costs. Presented results can indicate importance of those factors already at the design phase of new buildings. Consideration of those factors could lead to the rationalization of maintenance and operations costs of buildings with similar purpose. Further research should be directed at extending maintenance and operations costs database and tests of applicability of proposed model on buildings with similar purposes and buildings at other Universities. Further on it should be extended at various types of buildings regarding their purpose such as residential buildings, commercial buildings and/or industrial buildings, as well as at the types of inspections conducted and the types of errors that affect the functionality of the buildings parts and related costs.

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