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Construction-Duration Prediction Model for Residential Buildings in Slovak Republic Based on Computer Simulation

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Abstract

Very common problem in construction industry in Slovak republic, but also in the whole world, is contract time overrun. Inaccurate estimation of contractual construction time is one of the reasons of this problem. Many studies from all over the world show, there is a strong relationship between construction time and other construction parameters. This relationship is used for construction time prediction in the first phase of construction project. In order to fill the gap in construction duration estimating in Slovak construction conditions, the purpose of this study is to present developed prediction model based on computer experiment, considering gross floor area, number of stories and floor area of one storey as variable inputs in prediction while taking into account the intensity of the deployment of labour resources. Set of data is collected as a result of computer experiment and multiple linear regression analysis is used to define construction time prediction model. This model can be used by investor or constructor for fast and relatively accurate contractual construction time estimation for residential buildings. Methodology of mentioned prediction model could be used in the future for defining models for construction time estimation also for other construction sector.

Keywords: Construction time estimation; prediction model; residential buildings; construction management; construction planning

INTRODUCTION

Construction process is relatively complicated process that consists of several parts, structures, which are interconnected and it is always necessary to solve the structure of the construction process in relation to each other as well as with regard to the ambient conditions of construction. The structures have their construction process parameters that are interacting. Construction time has been pointed by most researchers as one of the key parameter of a successful project and it is influenced by several factors such as technology, process mechanization, project management, construction cost etc. Very common problem in construction industry in many countries of the world is contract time overrun. Construction delays may emanate from a diversity of origins including contractor´s faults, changes in design, other unforeseen events such as inclement weather and industrial relations disputes or just simply an overly optimistic predetermined contract duration [1]. Accurate estimate of construction time is very important in negotiating contract terms and there are several methods of estimation but according to Lin et al. [2] in practice, the most of them depends on the subjective skills and cognition of the estimators and planners, rather than on objective assessment.

In the construction industry, contractors usually use previous experiences to estimate the project duration of a new project [3, 4]. Such an estimate is relatively fast, but its accuracy is questionable. Another possibility is to determine the construction time using the construction process modeling software. It is more accurate but can be time consuming.

Preliminary, fast and reliable estimation of the construction duration is very important. One of the first who tried to define mathematical formula for construction time prediction was Bromilow [5]. His study in 1969 revealed that the time taken to construct a project is highly correlated with the size as measured by cost. Construction time in working days could be expressed as a function of cost based on the exponentional curve of best fit and upper and lower quartile limits derived from the historical data [1]. On this basis Bromilow´s time-cost model (BTC model) was defined as follow:

$$T = K \times C^B \tag{1}$$

where T = construction time (in days),

C= estimated cost of project (in million dollar),

K= a constant describing the general level of time performance,

B= a constant describing how the time performance was affected by project size as measured by cost.

The constants K and B may vary depending on the construction conditions of the country, but also depending on the construction sector. As already mentioned BTC model was several times validated and adapted for different countries by many researchers [1, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15]. The results of some studies from all over the world are summarized in table 1.

Table 1: The results of some studies – K and B values for BTC models in different countries and construction sectors

Researcher	Year	Country	Construction sector	Unit of measure	K	B
Bromilow	1969	Australia	Public projects Private projects Overall projects	million dollar	211 156 177	0.30 0.30 0.30
Bromilow	1974	Australia	Overall projects	million dollar	313	0.30
Ireland	1983	Australia	Overall projects	million dollar	155	0.47
Ireland	1985	Australia	High-rise buildings	million dollar	219	0.47
Bromilow	1988	Australia	Public projects Private projects Overall projects	million dollar	186 136 164	0.38 0.28 0.30
Kaka and Price	1991	United Kingdom	Public projects Private projects	-	398 274	0.32 0.21
Yeong	1994	Australia Malayzia	Overall projects Public projects	million dollar	269 518	0.21 0.35
Kumaraswamy and Chan	1995	Hong Kong	Public projects Private projects	-	188 160	0.26 0.31
Ng, Mak, Skitmore, Varnam	1998	Australia	Public projects Private projects Overall projects	million dollar	129 132 131	0.32 0.30 0.31
Chan	1999	Hong Kong	Public projects Private projects Overall projects	-	166 120 152	0.28 0.34 0.29
Chan	2001	Malayzia	Overall projects	-	269	0.34
Choudhury et al	2002	Bangladesh	Health sector	-	5	0.27
Choudhury and Rajan	2003	Texas, USA	Residential construction	thousand dollar	19	0.39
Czarnigowska and Sobotka	2009	Poland	Road	thousand Polish zloty	3	0.46
Zujo, Diana	2009	Bosnia and Herzegovina	New construction Reconstruction	100 thousand convertible mark	70 79	0.52 0.41
Bayram	2016	Turkey	Public projects (contract) Public projects (actual)	thousand Turkish lira	192 209	0.46 0.35

The most studies confirmed that the model defined by Bromilow is useful and the construction time estimation can be done by BTC model. However, the results of some studies for example from Nigeria and Ghana [16, 17] show that the relationship between construction time and construction cost showed very little correlation coefficient. Based on this, we can argue, that the BTC model is not applicable in some construction conditions in some countries. In Slovakia Mackova and Baskova [18] adopted BTC model in Slovakia and they defined prediction model for construction time of residential buildings in Slovak construction conditions in the next form with adjusted R Square = 0.768.

$$T = 384 \times C^{0.26} \quad (2)$$

where *T = construction time (in days),* *C= estimated cost of project (in million EUR).*

Many researchers [19, 20, 21, 22, 23, 24, 25] were also interested in whether construction cost is just an appropriate input for estimating the construction time. They tried to supplement or replace variable “cost” in BTC model. The summary of examined inputs is in the table 2.

Table 2: Summary of different inputs in prediction models

Author	Year	Country	Inputs
Bromilow et al.	1980	Australia	construction cost, type of investor
Nkado	1992	-	construction cost, investor requirements, project type, management
Walker	1995	Australia	construction cost, investor requirements, management, communication between participants, use of information technologies
Chan, Kumaraswamy	1995	Hong Kong	type of investor, construction cost, project type, gross floor area, number of floors
Chan	1999	Hong Kong	construction cost, type of investor
Chan, Kumaraswamy	1999	Hong Kong	envelope structure area, number of floors, gross floor area, prefabrication, type of construction, foundation, communication between participants
Boussabaine	2001		construction cost, type of investor, supplier
Ng, Skitmore	2003	Australia	construction cost, investor, construction segment
Chan, Chan	2004	Hong Kong	construction cost, gross floor area, number of floors
Love	2005	Australia	number of floors, project type, type of investor, gross floor area
Hoffman et al.	2007	-	construction cost, gross floor area, number of floors
Stoy et al.	2007	Germany	gross floor area, number of winters, planning time
Choudhury	2012	Texas, USA	construction cost, gross floor area, number of floors
Hoai et al.	2013	Vietnam	foundation, management, accuracy and completeness of the project, competence of subcontractors, type of investor

Mentioned authors surveyed, if there is better input for construction time estimation as construction cost and their results were different. For example, Le-Hoai et al. [24] claim, that there are many influencing inputs (type of foundation, project management, accuracy and completeness of the project, competence of subcontractors, type of investor) and they have to be implemented to the prediction model for construction time estimation. Other, for example Choudhury [23] in his study demonstrated, that it is appropriate to estimate construction time when gross floor area is known and he replaced input “cost” in BTC model by gross floor area.

In 2014 on author´s workplace (Institute of Construction Technology and Management at the Faculty of Civil Engineering, Technical University in Kosice in Slovakia) was also investigated replacement of the input “cost” in BTC model by input “gross floor area” and also to examine the construction time dependence on “cost” and the “gross floor area” simultaneously. As a result of research it was found that construction time estimation of residential buildings in Slovak construction conditions may be done by model (formula 3) with variable “gross floor area”.

$$T = 237 \times GFA^{0.25} \qquad (3)$$

where *T = construction time (in days),*

GFA= gross floor area of project (in thousand m^2).

However, this prediction model cannot be considered very reliable because of its adjusted R Square = 0.535. The R Square value shows that only 53% of all residential buildings and its construction time can be expressed by prediction model with “gross floor area” as independent variable. In mentioned research it was also found that construction-duration prediction model, where independent variables were defined as “cost” and the “gross floor area” simultaneously, has no relevance. Statistical analysis by software SPSS demonstrated, that variable “gross floor area” is not statistically significant in this model at five % significance level.

The aim of this study is to present another prediction model for estimating the construction time of residential buildings in Slovakia with higher predictive ability that models mentioned above.

The model was created through computer simulation (experiment) and the subsequent compilation of mathematical model. Prediction model takes account multiple input variables simultaneously. Subsequently, this model is compared from the view of the predictive ability with two already existing models (formulas 2, 3) for estimating the construction time of residential buildings in Slovak construction conditions.

RESEARCH METHODOLOGY

Creating a mathematical model begins by variables defining. Firstly it was necessary to identify construction process parameters that can significantly affect the process of construction and choose the inputs that will be the subject of modeling. In 2015 Institute of Construction Technology and Management at the Faculty of Civil Engineering, Technical University in Kosice has done the research of crucial construction process parameters identification. Electronic questionnaire survey, as one of the most used research instrument, was used. This method of gathering information from respondents is very simple and relevant and questioner does not have to spend much time by personal questioning. Questionnaire was divided in several parts. The first part was focused on general information about the respondent and about the construction enterprise in which respondent works. There were interviewed the construction companies dealing with the realization of structures. Other three parts were focused on the interactions of construction process parameters. As one of the questionnaire survey results, the variables for prediction model (for construction time estimation) were defined. Electronic questionnaire was sent to 146 respondents of small and medium-sized construction companies. Forty-seven respondents (32% of interviewed) participated in this research. The survey sample was made up of 80% of respondents from small construction companies (companies up to 49 employees) and 20% of respondents from medium-sized construction companies (firms 50 to 249 employees). Respondents answered the questions about the interaction of construction parameters on construction time based on their own experience from practice and they had to comment the possible impacts of the construction parameters on the construction time. They also had to select from the various alternatives, construction parameters according which it would be appropriate to estimate construction duration. The aim of presented questionnaire survey was to define the variables for construction time estimating model of construction projects in Slovak construction market. Based on the evaluation of the respondent's answers, variables for prediction model concerning residential buildings were defined as follow: number of stories and floor area of one storey.

We decided to use a computer simulation in order to obtain various models of residential buildings. In this study, software CONTEC [26] was used for construction process modelling. Software CONTEC was developed specifically for construction process scheduling and planning and it is possible to simulate construction process taking account parameters mentioned above. CONTEC also allows changing the intensity of the labor resources deployment in construction process, such as through adjusting the number of workers in teams or changing weekly time funds.

Firstly, it was necessary to create construction process model of residential building with defined sub-processes and technological and organizational interconnections between them. Model was created for one of the most used construction system of residential buildings in Slovakia - reinforced concrete system.

Subsequently, construction process model input parameters, which will be exchanged within computer experimentation, was defined. Also the intervals at which they can take their values were identified:

- building volume [m^3] - in the range from 600 to 60 000 m^3 (calculated from the total floor area of the building and the overall height of one storey, which is 3m, while the floor area of each storey is increased gradually by 200 m^2 in the interval from 200 m^2 to 2 000 m^2),
- number of stories - from 4 storey to 18 stories,
- weekly time funds [hours] - 40 hours per week or 56 hours per week ,
- intensity of the labour resources deployment in construction process – typical composition of the work teams and twice the number of workers in teams.

For each variant of residential building with a certain floor area was necessary to create model which is called "a base model". "Base model" is construction process model which considers standard weekly time funds (40 hours per week). Subsequently by successive amendments (using computer simulation) were done modifications of basic model (taking into account a variant intensity of deployment labor resources in construction process). In total, it was done three hundred simulations in all for all variants of stories and floor area. Obtained data about construction time for all modelled variants of residential buildings were summarized and multiple regression analysis by software SPSS was used for the determination of construction-duration prediction model. Afterwards, model was compared with two models for construction time estimation for residential buildings in Slovakia mentioned above (formula 2, 3).

RESULTS AND DISCUSSION

Three hundred simulations of construction process of residential buildings were done in order to get data for multiple regression analysis. The obtained data included the "number of floors" (NOF), "floor area of one storey" (FA), as well as the construction duration of each building project. A summary of the modelled projects characteristics is shown in Table 3.

Table 3: Characteristics of modelled residential building projects, N=300

Project type	number of floors (NOF)	number of projects	% of projects	foor area (FA) of one storey [m^2]	number of projects	% of projects
Residential building	4	7	2.3	< 200	0	0.0
	5	15	5.0	200-400	45	15.0
	6	39	13.0	400-600	48	16.0
	7	48	16.0	600-800	36	12.0
	8	37	12.3	800-1000	35	11.7
	9	30	10.0	1000-1500	36	12.0
	10	23	7.7	1500-2000	22	7.3
	11	28	9.3	2000-2500	19	6.3
	12	11	3.7	2500-3000	18	6.0
	13	16	5.3	3000-3500	9	3.0
	14	8	2.7	3500-4000	11	3.7
	15	13	4.3	4000-4500	6	2.0
	16	9	3.0	5000-5500	8	2.7
	17	7	2.3	5500-6000	7	2.3
	18	9	3.0	>6000	0	0.0

Data from these construction projects of residential buildings were used for developing the construction-duration prediction model for this type of projects. First of all, scatter plots (figure 1, 2) of obtained data (construction duration against number of floors and floor area of one storey) were done. One of the most powerful aspects of a scatter plot is ability to show relationships between variables. On the horizontal axis were displayed values of construction time in days and on the vertical axis were displayed values of number of floors and floor area of one storey, respectively. According to scatter plots we can assume that there could be significant dependency between observed parameters. It can be expected that there is exponential dependency between construction duration against number of floors and floor area of one storey.

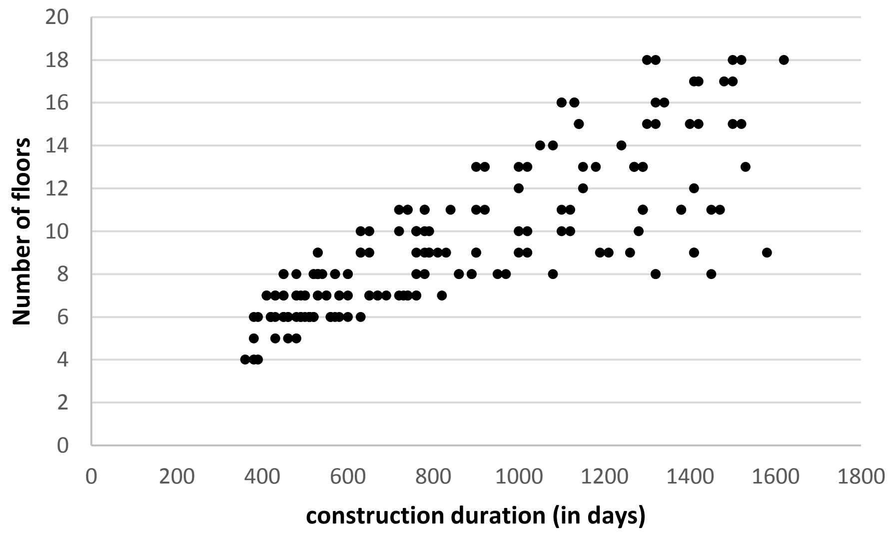

Figure 1: Scatter plot of construction duration against number of floors

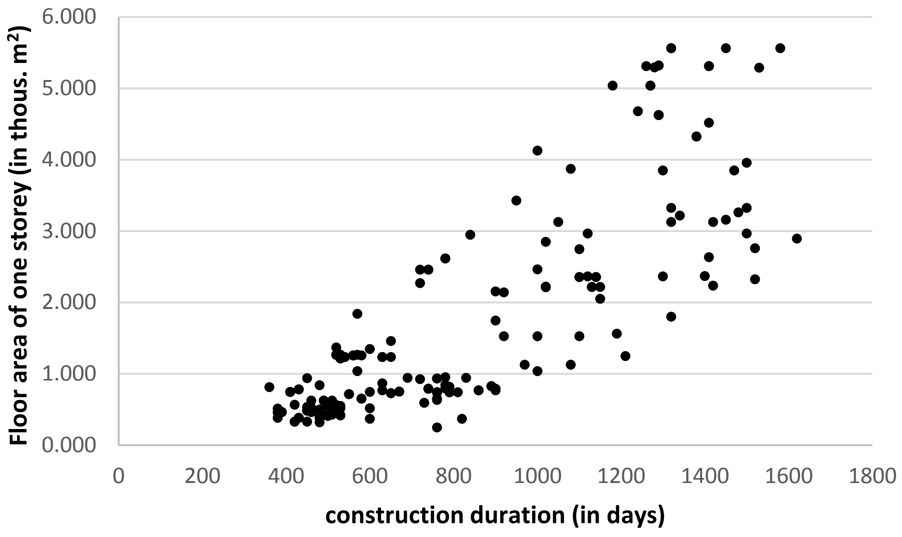

Figure 2: Scatter plot of construction duration against floor area of one storey

Based on this we can define the effect of floor area and number of floors on construction duration in form:

$$T = K \times NOF^{B1} \times FA^{B2} \quad (4)$$

where T = construction time (in days),

NOF = number of floors,

FA =floor area of one storey (in thousand m²),

K, B1, B2 = coefficients expressing the dependency between variables.

Regression analysis was used for defining the coefficients K, B1, B2 in formula 4. However in order to use multiple linear regression analysis it is necessary to linearize formula 4 to form:

$$lnT = lnK + B1 \times lnNOF + B2 \times lnFA \quad (5)$$

where lnT = natural logarithm of construction time,

lnNOF = natural logarithm of number of floors,

lnFA = natural logarithm of floor area of one storey,

lnK = natural logarithm of constant K,

B1, B2 = coefficients.

The scatter plots of relationship between natural logarithm of construction time and natural logarithm of floor area of one storey and between natural logarithm of construction time and natural logarithm of number of floors are shown in figures 3 and 4 respectively.

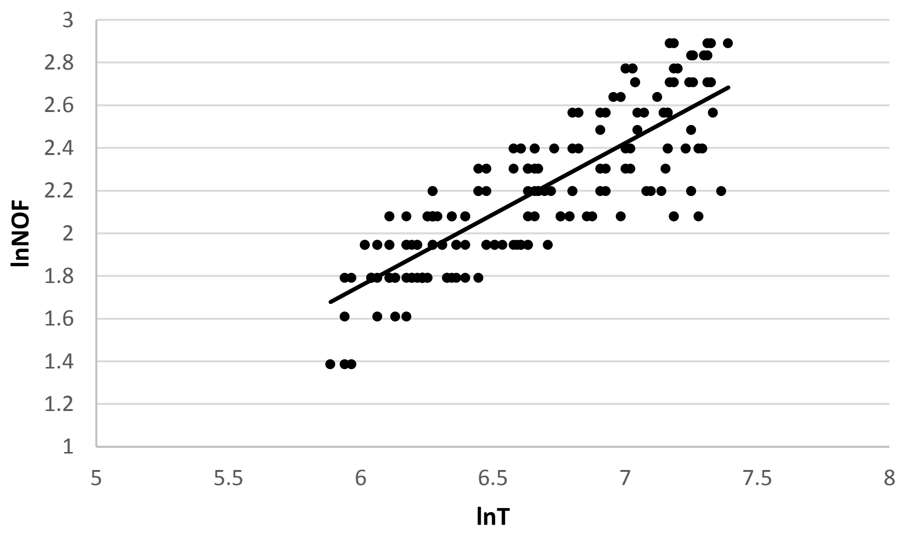

Figure 3: Scatter plot of lnT against lnNOF

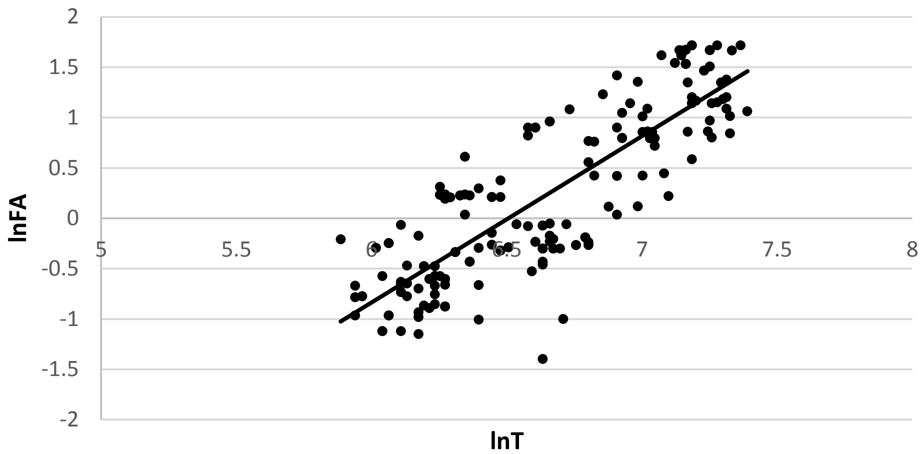

Figure 4: Scatter plot of lnT against lnFA

It is evident that there is a linear dependency between these transformed forms of variables. Multiple linear regression by software SPSS analysis was therefore used. Multiple regression model was identified and analyzed.

It was established the null hypothesis H_0: There is no significant relationship between the dependent variable (natural logarithm of construction time) and independent variables (natural logarithm of number of floors and natural logarithm of floor area of one storey). Analysis of variance (ANOVA) was used for the hypothesis test at five % significance level. According to F-calculated value, which is higher than F-tabulated, we can reject null hypothesis and we accept alternative hypothesis H_1: There is significant relationship between the dependent variable (natural logarithm of construction time) and independent variables (natural logarithm of number of floors and natural logarithm of floor area of one storey).

Regression statistics of determined prediction model (formula 5) is shown in Table 4.

Table 4: Regression statistics of model

lnK	5.017
B1	0.642
B2	0.211
Multiple R	0.899
R Square	0.808
Adjusted R Square	0.806
Standard Error	0.185
Significance (F)	0.000

The value of R Square indicates high predictability of regression model. If this value is 1, it means that there is a perfect relation between dependent and independent variables in the regression model. On the other hand, if the value of R Square is 0, there is no relation between variables. Because of the R Square value of 0.808 we can claim, that at least 80 percent of the variances in construction duration of residential buildings can be explained by variables number of floors and floor area of one storey.

Based on the results of regression analysis we can define coefficients K, B1 and B2. The value of K can be expressed through exponential function from the value of lnK. As we can see in Table 4, the value of lnK = 5.017, so K value is 151. Coefficients B1 and B2 express dependency of variable construction time (T) from variables number of floors (NOF) and floor area of one storey (FA). Construction-duration prediction model then can be expressed as follows:

$$T = 151 \times NOF^{0.64} \times FA^{0.29} \quad (6)$$

where T *= construction time (in days),*

NOF = number of floors,

FA =floor area of one storey (in thousand m^2*).*

To find out whether construction-duration prediction model in form expressed by formula 6 is more accurate for construction time estimation for residential buildings in Slovakia then prediction models expressed by formulas 2, 3, comparison had to be made. Data from real construction projects (50 projects summarized in Table 5) of residential buildings completed between the years 2010 and 2016 in Slovakia were used for these three models comparison. Construction projects were collected from all regions of Slovakia.

Table 5: Characteristics of real residential building projects, N=50

Construction time (T) (days)	No. of projects	% of projects	number of floors (NOF)	No. of projects	% of projects	floor area (FA) of one storey	No. of projects	% of projects
< 200	0	0.0	4	1	4.0	< 200	0	0
200-300	0	0.0	5	3	4.0	200-400	4	8
300-400	6	12.0	6	7	12.0	400-600	4	8
400-500	5	10.0	7	8	12.0	600-800	5	10
500-600	7	14.0	8	6	14.0	800-1000	3	6
600-700	4	8.0	9	5	8.0	1000-1500	4	8
700-800	6	12.0	10	4	10.0	1500-2000	2	4
800-900	5	10.0	11	5	10.0	2000-2500	4	8
900-1000	2	4.0	12	2	4.0	2500-3000	4	8
1000-1100	1	2.0	13	3	4.0	3000-3500	5	10
1100-1200	2	4.0	14	1	6.0	3500-4000	6	12
1200-1300	2	4.0	15	2	2.0	4000-4500	3	6
1300-1400	4	8.0	16	2	2.0	5000-5500	3	6
1400-1500	5	10.0	17	1	6.0	5500-6000	2	4
>1500	1	2.0	18	2	2.0	>6000	1	2

Construction durations of all projects were calculated by all models (formulas 2, 3, 6). Subsequently, the real construction time was compared with predicted construction time. Two standard error measures, root mean square error (RMSE in days) and mean absolute percentage error (MAPE in %) were calculated by formulas:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(x_{real,i} - x_{predicted,i})^2}{n}} \quad (7)$$

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left(\left|\frac{x_{real,i} - x_{predicted,i}}{y_{real}}\right| \times 100\right) \quad (8)$$

where

$x_{real,i}$ = *real observed value of construction time (days),*

$x_{predictedl,i}$ = *construction time calculated by prediction models (days),*

n = number of observations.

RMSE measures the differences between construction time predicted by a model and the construction time actually observed and MAPE is a measure of prediction accuracy of a forecasting model. The values of R Square of prediction models were also compared. The most accurate model is those, which RMSE and MAPE values are closer to zero and R Square value is closer to one. Summary of calculated values (RMSE, MAPE, R Square) for all prediction models is shown in Table 6.

Table 6: Comparison of construction-duration prediction models for residential buildings in Slovakia, N=50

Dependent variable	Independent variables	Model	Reference data		
			RMSE (days)	MAPE (%)	R Square
Construction duration	Construction cost	$T = 384 \times C^{0.26}$	72	13.4	0.768
	Gross floor area	$T = 237 \times GFA^{0.25}$	113	20.9	0.535
	Number of floors, floor area	$\boldsymbol{T = 151 \times NOF^{0.64} \times FA^{0.29}}$	**60**	**12.3**	**0.808**

Based on RMSE, MAPE and R Square values comparison (Table 6) we can claim that the most accurate model is those with number of floors and floor area of one storey as independent variables. This model has the least RMSE (60 days) and MAPE (12.3%) values and the R Square value (0.808) of this model is the most. It means that construction time of 80% residential buildings in Slovakia can be expressed by this mathematical model. However construction-duration prediction model in this form is not generally applicable. Because of different national standards and productivity of the workforce, prediction model in present form can be used only for estimating the construction time of residential buildings in Slovakia. Methodology of prediction model creating could be used in the future for defining models for construction time estimation also for other construction sector in Slovakia or for construction-duration prediction model in other country.

CONCLUSION

The aim of submitted study was to present a prediction model for construction time estimation for residential buildings in Slovakia based on data obtained from computer experiment. Variables (number of floors and floor area of one storey) in this model of construction time estimation were defined by respondents from Slovak construction companies through questionnaire survey done in 2015 on Institute of Construction Technology and Management at the Faculty of Civil Engineering, Technical University in Kosice. Results of this research pointed to fact that for constructors and investors it would be very helpful to have construction-duration prediction model including these parameters as independent variables. In order to obtain the data necessary for prediction model creating, software CONTEC was used. It was done three hundred simulations of various residential buildings and the data about construction time, number of floors and floor area of one storey were collected and then analysed. Subsequently, using multiple regression analysis, mathematical model mentioned above was created. In order to find out, whether the prediction model has higher predictive ability than already existing prediction models in Slovakia, models have to be compared. Comparison was done through values of two standard error measures, root mean square error (RMSE) and mean absolute percentage error (MAPE) and through value of R Square of models. Already existing models include construction cost and gross floor area as independent variables. Comparison of three predictions models for residential buildings in Slovakia pointed to the fact, that estimating of construction time by prediction model with the gross floor area as independent variable is not enough accurate. R Square of this model with value 0.535 is relatively low and model provides estimation of construction time with 113 days average error. Also the values of MAPE and RMSE are higher than values of other two prediction models. Because of this, it can be concluded that, it would be very inaccurate to use this model for estimating construction time of residential buildings in Slovakia. Statistical analysis of prediction models showed that model with construction cost as independent variable (adapted BTC model) is more accurate. This model with R Square value of 0.768 provides estimation of construction time with 72 days average error. Using created construction-duration prediction model, it is possible to estimate construction time of residential buildings in the first phase of construction project, when the number of floors and floor area of one storey is known. By statistical analysis and comparison of all prediction models defined for residential buildings in Slovak construction conditions it was found, that the last mentioned prediction model has the highest predictive ability. R Square value 0.808 is the highest at all and this mathematical model provides estimation of construction time with 60 days average error. Currently, there is very common problem of accurate estimation of contractual construction time in Slovakia. Just in order to fill the gap in this field the prediction model was developed. This model can be used by investor or constructor for fast and relatively accurate contractual construction time estimation for residential buildings in Slovakia. Presented construction-duration prediction model in this form is not generally applicable. Each country has its own national standards and productivity of the workforce, thus prediction model in present form can be used only for estimating the construction time of residential buildings in Slovakia. On the other hand, methodology of prediction model creating could be used in the future for defining models for construction time estimation also for other construction sector in Slovakia or for construction-duration prediction model in other country.

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REFERENCES

[1] Ng, S.T., Mak, M., Skitmore, R.M., Varnam, M., 2001, "The Predictive Ability of Bromilow's Time-Cost Model," Construction Management and Econonics, Vol. 19, No. 2, pp. 165-173, DOI: 10.1080/01446190150505090.

[2] Lin M.-Ch. et al., 2011, "Developing a construction-duration model based on a historical dataset for building project," Journal of Civil Engineering and Management, Vol. 17, No. 4, pp. 529-539, DOI: 10.3846/13923730.2011.625641.

[3] Choudhury, I. And Rajan, S.S., 2003, "Time-cost relationship for residential construction in Texas," 20th International Conference on Construction IT, Construction IT Bridging the Distance, Waiheke Island, New Zeland.

[4] Endut, I. R., Akintoye, A. and Kelly, J., 2006, "Relationship between duration and cost of Malaysian construction projects," International Conference in the Built Environment in the 21st Century, Kuala Lumpur, Malaysia, pp. 299-309.

[5] Bromilow, F.J., 1969, "Contract time performance: Expectations and the reality," Building forum, Vol. 1, No. 3, pp. 70-80.

[6] Bromilow, F.J., 1974, "Measurement and scheduling of construction time and cost performance in the building industry," The chartered builder 1974, Vol. 10, No. 9, pp. 79-82.

[7] Ireland, V., 1985, "The role of managerial actions in the cost, time and quality performance of high-rise commercial building projects," Construction Management and Economics, Vol. 3, No. 4, pp. 59-87, DOI: 10.1080/01446198500000006.

[8] Kaka, A. P. and Price, A. D. F., 1991, "Relationship between value and duration of construction projects," Construction Management and Economics, Vol. 9, No. 4, pp. 383-400, DOI: 0.1080/01446199100000030.

[9] Yeong, C. M., 1994, "Time and cost performance of building contracts in Australia and Malysia," M.Sc.Thesis, University of South Australia, Adelaide, Australia.

[10] Chan, A. P. C., 1999, "Modelling building durations in Hong Kong," Construction Management and Economics, Vol.17, No. 2, pp. 189-196, DOI: 10.1080/014461999371682.

[11] Chan, A. P. C., 2001, "Time-cost relationship of public sector projects in Malaysia," International Journal of Project Management, Vol. 19, No. 4, pp. 223-229, DOI: 0.1016/S0263-7863(99)00072-1.

[12] Choudhury, I., Rajan, S.S., 2004, "Time-cost relationship for residential construction in Texas," 20th International Conference on Construction IT, Construction IT Bridging the Distance, Waiheke Island, New Zealand.

[13] Abraham, A., 2008, "Time-cost relationship for public road construction projects in Ethiopia," Addis Ababa University School of Graduate Studies.

[14] Zujo, V., Diana, C. P., 2009, "Application of „time-cost" model in construction project management," http://bib.irb.hr/datoteka/444400.92-ujo-Car-Pui.pdf.

[15] Bayram, S., 2016, "Duration prediction models for construction projects: in terms of cost or physical characteristics?" KSCE Journal of Civil Engineering, KSCE, In press, pp. 1-12, DOI: 10.1007/s12205-016-0691-2.

[16] Ogunsemi, D.R., Jagboro, G.O., 2006, "Time-cost model for building projects in Nigeria," Construction Management and Econonics, Vol. 24, No. 3, pp. 253-258, DOI: 0.1080/01446190500521041.

[17] Ameyaw, C., MensaH, S., Arthur, Y.D., 2012, "Applicability of Bromilow´s time-cost model on building projects in Ghana," Proc 4th West Africa Environment Research Conference, Abuja, Nigeria, pp. 881-888.

[18] Mackova, D and Baskova, R., 2014, "Applicability of Bromilow´s time-cost model for residential projects in Slovakia," Selected Scientific Papers – Journal of Civil Engineering. Vol. 9, No. 2, pp. 5-12, DOI: 0.2478/sspjce-2014-0011.

[19] Walker, D.H.T., 1995, "An investigation into construction time performance," Construction Management and Economics, Vol. 13, No. 3, pp. 263-274, DOI: 10.1080/01446199500000030.

[20] Chan, D. W. M. and Kumaraswamy, M. M., 1999, "Modelling and predicting construction durations in Hong Kong public housing," Construction Management and Economics, Vol. 17, No. 3, pp. 351-362, DOI: 0.1080/014461999371556.

[21] Love, P.E.D., Tse, R.Y.C., Edwards, D.J., 2005, "Time-cost relationship in Australian construction projects," Journal of Construction Engineering and Management, Vol. 131, No. 2, pp. 187-193, DOI: 10.1061/(ASCE)0733-9364(2005)131:2(187).

[22] Hoffman, G. J., Thal, A. E., Webb, T. S., and Weir, J. D., 2007, "Estimating performance time for construction projects," Journal of Management in Engineering (ASCE), Vol. 23, No. 4, pp. 193-199, DOI: 0.1061/(ASCE)0742-597X(2007)23:4(193).

[23] Choudhury, I., 2012, "A study of the factors of construction time for educational projects in Texas," Texas A&M University.

[24] Le-Hoai, L., Lee, Y.D., Nguyen, A.T., 2013, "Estimating time performance for building construction projects in Vietnam," KSCE Journal of Civil Engineering, Vol. 17, No. 1, pp. 1-8, DOI: 10.1007/s12205-013-0862-3.

[25] Stoy, Ch., Pollalis, S., Schalcher, H.-R., 2007, "Early estimation of building construction speed in Germany," International Journal of Project Management, Vol. 25, No. 3, pp. 283-289, DOI: 10.1016/j.ijproman.2006.11.010.

[26] Software CONTEC: Available from: http://www.contec.cz/ [Accessed 30 January 2017].