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MATHEMATICAL MODELING OF THE FORECASTING OF THE CONSTRUCTION WASTE REUSAGE OCCURRENCE

Object of the research is building waste, annual volume of the building waste in Ukraine is almost 1 mil. t., and the increment of the land areas, occupied by the building waste is 50000 ha. According to the world practice nearly 90 % of the building waste are to be recycled and reused. That is why, the forecast of the dependence of the construction waste reusage occurrence in various countries of the world on the basic parameters of influence in order to develop the strategy of building waste management is an important scientific engineering problem. The study of the reusage of construction waste occurrence in different countries is carried out by planning the experiment of the second order, applying Box-Wilson method by means of the central composite rotatable design (CCDD), using the developed software, protected by the certificate of the State Registration of the right to the copyright object.

Aim of the research is the determination of the regression model for the forecasting of the dependence of the construction waste reusage occurrence in different countries on the basic parameters of impact. Regressional dependence of the forecast of the construction waste reusage occurrence on the basic parameters of impact is obtained: density of the country's population, amount of the gross domestic product per capita, human development index, average geographical latitude. It is determined that, according to Fishers criterion, the hypothesis of the adequacy of the obtained regression model can be considered to be correct if the validity is 95%. Correlation coefficient is 0.99934, this proves the sufficient reliability of the obtained results. Obtained regressional dependence can be used for the development of the strategy for the building waste management. It was determined, that among the considered factors of impact, the value of gross domestic product per capita has the greatest impact, and the average geographical latitude has the least impact. Response surfaces of the objective function – occurrence of the construction waste reusage and their 2D cross-sections in the planes of the impact parameters are constructed.

Key words: *mathematical modeling, experiment planning, multifactorial dependence, impact factors, response surface, occurrence forecast, reusage, construction, building waste, materials science.*

Introduction

Nowadays the construction waste becomes an urgent problem, annual volume of the waste of Ukraine, according to the information of the Ministry of the environmental protection is almost 1 mil. tons. Annual growth of areas, occupied by the waste, is 50 ths. ha [1]. Construction waste can be widely used in the sphere of civil engineering for obtaining valuable materials: filler [2] and binding [3 – 5] for the production of concrete, dry building mixtures and other construction materials [6, 7], for the production of the construction materials with the protective properties against the electromagnetic radiation [8, 9] and static electricity [10], for the manufacturing of the anodic earthings [11]. Many mineral and organic waste by their chemical composition and technical properties are close to natural raw materials.

Problem set up

In the world practice almost 90 % of the construction waste are recycled and reused. That is why, forecasting of the dependence of the reusage occurrence of the construction waste in different countries of the world on basic impact parameter in order to develop the strategy of the building waste management is an important scientific-engineering problem.

Analysis of the recent studies and publications

In the work [2] slurryashcarbonate press-concrete is proposed, it consists of the waste of the stone carving of the carbonate rocks, fly-ash of Ladyzhyn thermal power plant, red mud of Mykolaiv alumina refinery plant with the addition of portland cement. In the paper [3] it is shown

that the creation of new construction materials of the polyfunctional designation enables to solve urgent for Ukraine problem of energy and resource saving. Basic method of red mud disposal in the process of production of the construction materials is its usage as the modifying additive to ashcement binding [4]. In the research [5] metalashphosphate binding on the base of the industrial waste was proposed. Technical-economic expediency of wider usage of thermal station waste for the production on cement and other construction materials is shown in [6]. In the study [7] it is shown, that the obtaining of the concrete gravel, fine grained sifting and their reuse is a final stage of the closed cycle of the recycling of the concrete and reinforced concrete waste– «wear – transportation – recycling – realization». Application of the betal-m (electric conducting concrete, metal-saturated, used as a special covering for biological protection against ionizing radiation in the buildings and structures) of the cellular, variotropic and dense structure enables to decrease the level of electromagnetic radiation and reduce the danger of radiation [8]. The expediency of usage fine dispersive powders of steel IIIX-15 slur for the production of the special protective covering against electromagnetic radiation is substantiated in the study [9]. In the research [10] it is suggested to use the coating of electric conducting concrete to protect against the charges of static electricity, the technology of this coating production is rather simple and does not require expensive materials and special equipment. Betel-m can be used for the fabrication of electric conducting elements (anodic earthings), systems of anticorrosive cathode protection of the underground engineering networks [11].

The paper [12] contains statistical data, regarding the volumes of production, occurrence of the reusage of the building waste in different countries of the world. In the study [13] the regressional dependence, describing the dynamics of the volume of the construction, demolition waste formation in Vinnytsia Region is determined, the given dependence enables to forecast the mass of waste formation. In the work [14] regression model for the forecast of the volumes of construction, demolition waste production in different countries, depending on basic impact parameters. However, the authors did not find specific mathematical dependences of the reuse of the construction and demolition waste occurrence in different countries of the world on the basic impact parameters.

Aim and tasks of the study

Aim of the given study is the determination by means of planning of multifactor experiment the regression model for the forecasting of the dependence of the construction waste reuse occurrence in different countries of the world on main impact parameters.

Methods and materials

Determination of the regression model for the forecast of the dependence of the of construction waste reuse occurrence on basic impact parameters was carried out by means of central composite rotatable design of the second order, applying Box-Wilson method [15]. Determination of the coefficients of the regression equation was performed by means of the developed computer program "PlanExp", protected by the Certificate of the State Registration of the right to the copyright object [16] and is described in the papers [17, 18].

Results of the experimental studies

Among the parameters the occurrence of the occurrence waste in different countries depends on, the following parameters were considered: density of the country’s population, volume of gross domestic product per capita, human development index, average geographical latitude, values of these parameters are presented in Table 1. Unlike the absolute parameters, relative parameters allow to compare countries with different level of economic development and human potential, population, areas and climatic conditions.

Table 1

Occurrence of the construction waste usage in different countries of the world [12]

Country	Occurrence of construction waste reusage, %	Impact factors			
		Density of the population, people/km^2	GDP per capita, ths. $/pers.	Human development index	Average geographical latitude, ° n. l.
Japan	45	337	38.095	0.956	34.89
Germany	17	230	40.415	0.94	51.17
France	15	114	45.858	0.955	46.7
Korea	40	480	20.582	0.928	38.06
Italy	9	199,4	39.565	0.945	41.28
Spain	5	79.7	35.557	0.949	39.5
The Netherlands	90	394	51.657	0.958	52.15
Belgium	87	318	29.814	0.948	50.83
Portugal	5	114	22.232	0.795	39.69
Greece	5	85.3	30.661	0.947	39
Sweden	21	21.9	55.427	0.958	62.2
Norway	50	12	72.306	0.968	62
Finland	45	16	36.217	0.954	64.8
Ireland	5	60.3	43.6	0.96	53
Ukraine	4	76	7.532	0.786	48.38

According to the data of the Table 1 regression equation is obtained, it describes the dependence of the construction waste reuse occurrence in different countries of the world on main impact parameters and has the following form

$$O_{RBW} = 100.7\frac{GDP}{n_p} - 19.1\frac{n_p}{S_{cr}} - 133.3HDI + 0.7784L - 0.01055\frac{n_p}{S_{cr}}\frac{GDP}{n_p} + \\ + 20.16\frac{n_p}{S_{cr}}HDI - 108.4\frac{GDP}{n_p}HDI - 0.1961\frac{GDP}{n_p}L + 14.59HDI \cdot L + \\ + 0.001134\left(\frac{n_p}{S_{cr}}\right)^2 + 0.165\left(\frac{GDP}{n_p}\right)^2 - 122HDI^2 - 0.05764L^2 - 81.49 \quad , \quad (1)$$

where O_{RBW} – is the occurrence of building waste reuse, %; n_p/S_{cr} – is the population density of the country, people/km^2; GDP/n_p – is GDP per capita, ths. $/person; n_p – is the quantity of the population, people; S_{cr} – is the area of the country, km^2; HDI – is human development index (HDI = 0…1); L – is average geographical latitude.

By Student`s criterion it was established: all the factors, their pair interaction effects, except $n_p/S_{cr}L$, and quadratic effects turned out to be valid, the greatest occurrence of the building waste reuse in different countries of the world depends on GDP per capita and the least – on average geographical latitude.

It is established that by Fisher`s criterion the hypothesis of the adequacy of the regression model (1) can be considered to be correct with 95 % validity. Correlation coefficient was 0.99934, that proves the sufficient reliability of the obtained results.

Comparison of the actual and theoretical occurrence of the reuse of the construction waste in different countries of the world, ranking in the decreasing order, is presented in Fig. 1.

It is seen from Fig. 1, that the theoretical occurrence of the reuse of the construction waste in different countries of the world, calculated by means of the regressive model (1), does not differ greatly from the actual data [12]. This proves the sufficient reliability of the dependence, determined previously, that can be used for the development of the strategy of building waste management.

Fig. 2 presents the response surfaces of the objective function-occurrence of the construction waste reuse in different countries of the world and their 2D cross-sections in the planes of impact parameters, which enable to represent the dependence (1) and the character of the simultaneous impact of several factors on the objective function.

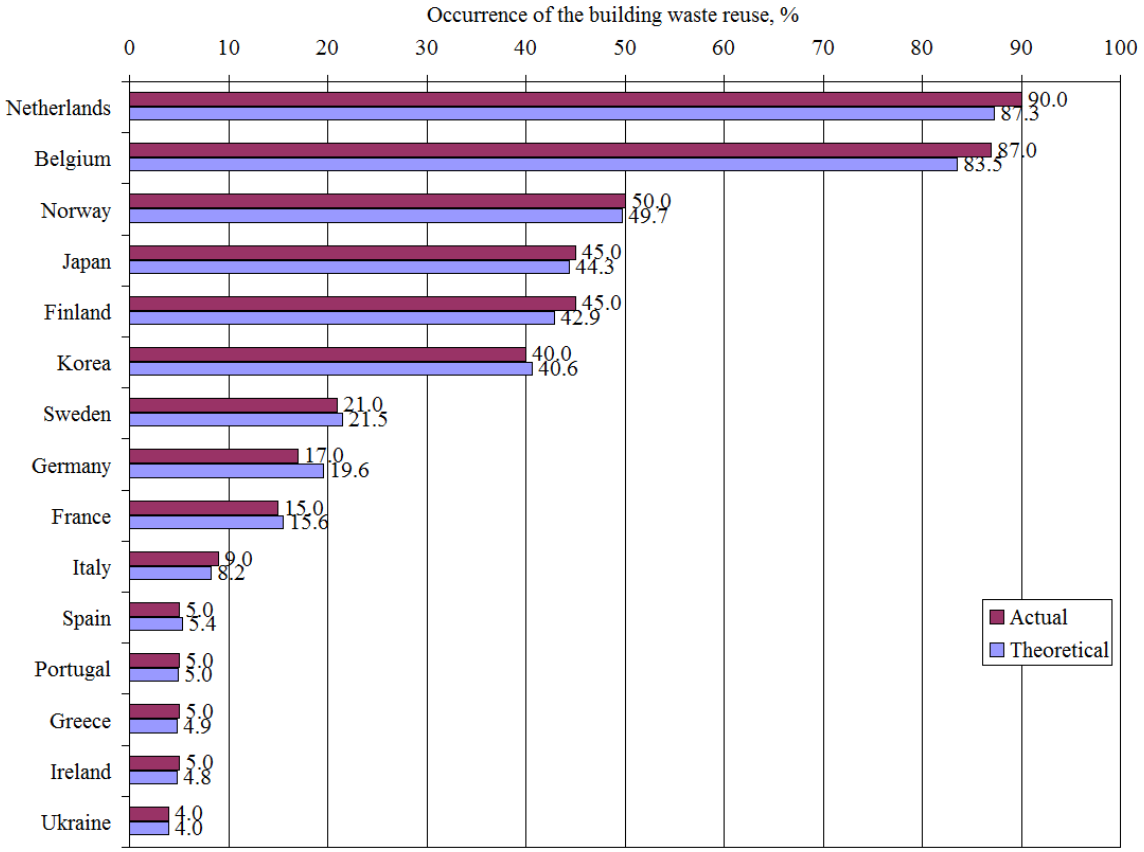

Fig. 1. Comparison of actual and theoretical occurrence of the reusage

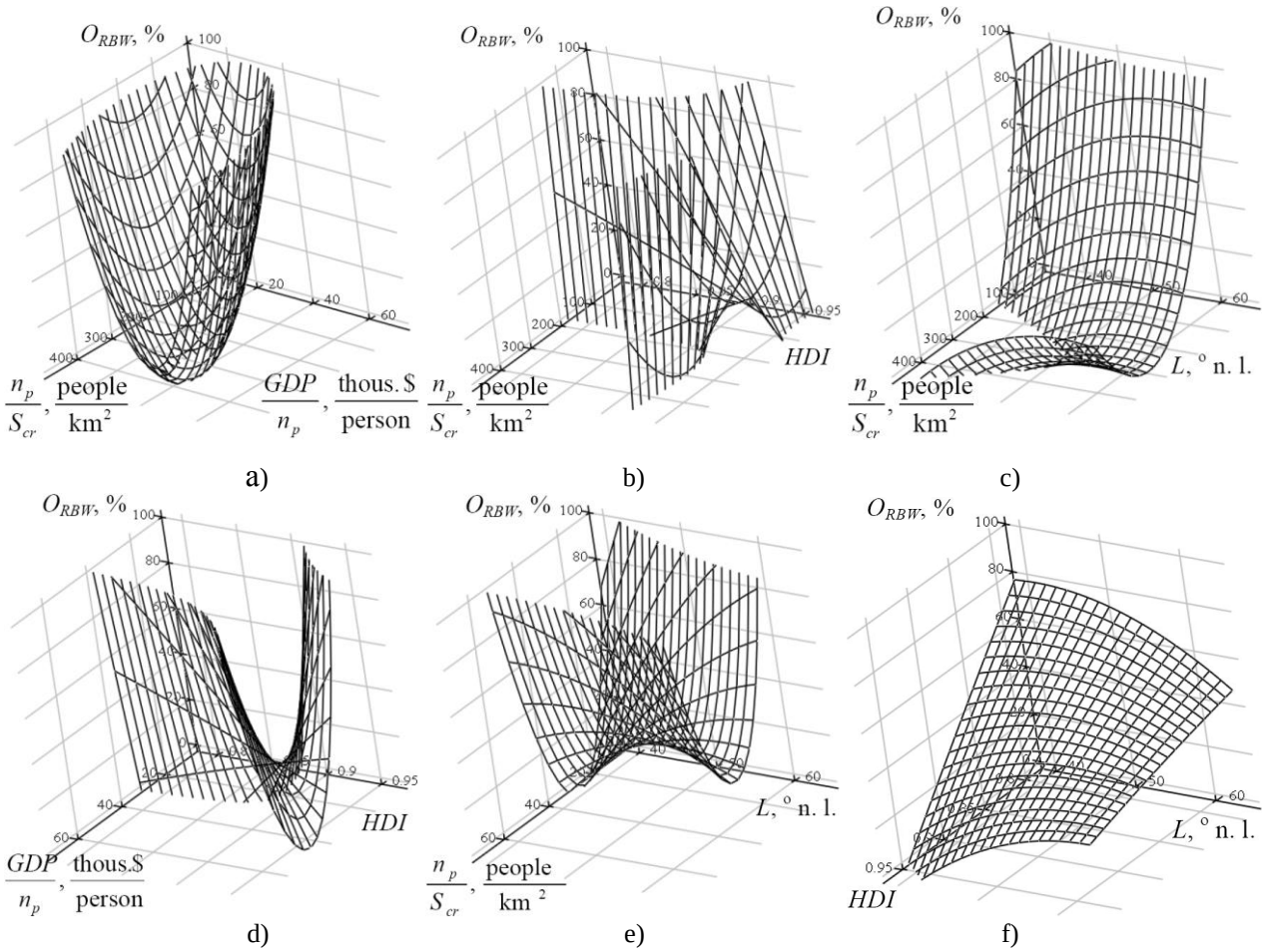

Fig. 2. Response surfaces of the objective function – occurrence of the building waste reusage in different countries of the world and their 2D cross-sections in the planes of impact parameters:

a) – $O_{RBW} = f\left(n_p / S_{cr}, GDP/n_p\right)$; b) – $O_{RBW} = f\left(n_p / S_{cr}, HDI\right)$; c) – $O_{RBW} = f\left(n_p / S_{cr}, L\right)$;

d) – $O_{RBW} = f\left(GDP/n_p, HDI\right)$; e) – $O_{RBW} = f\left(GDP/n_p, L\right)$; f) – $O_{RBW} = f\left(HDI, L\right)$

Conclusions

It is established that the following factors influence the occurrence of the construction waste reuse in different countries of the world; population density, value of gross domestic product per capita, human development index. Thereby, the value of gross domestic product per capita has the greatest impact on the occurrence of the building waste reuse and average latitude exercises the least impact.

Adequate mathematical model for the forecast of the occurrence of the building waste reuse in different countries of the world is obtained, it can be used in the process of the development of the strategy of the construction waste management.

Response surfaces of the objective function – occurrence of the building waste reuse in different countries of the world are constructed, they enable to illustrate clearly the dependence of this objective function on separate impact parameters.

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