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Anatoliy MOKIY[1], Yuriy PYNDA[2], Olha ILYASH[3], Mariia PIKH[4], Rostyslav PYNDA[5]

[1] Dolishniy Institute of Regional Research of National Academy of Sciences of Ukraine
[2] Lviv University of Business and Law
[3] National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", International University of Finance
[4] National University of Food Technologies, Lviv State College of Food and Processing Industry
[5] Lviv University of Business and Law

Characteristics of interconnections of construction sector and environment: regional study of Ukraine

Key words: construction sector, environment, ecosystem, interconnections, reveal systemic interconnections, regions

Introduction

The results of the global trends analysis in the construction industry confirm its evolving nature, namely through the prism of socio-economic priorities at to conserving energy and respecting the environment. For several decades, there have been three stages in the evolutionary development of construction, where each successive stage contains all the positive components of the previous one, enhancing and refining them. These stages include: energy efficient construction, especially in the context of the adopted Directive on energy efficiency of new buildings (Gumbarević, Milovanović, Bagarić, Gaši & Dunović, 2020), according to which EU Member States must be provided with zero energy buildings by 31 December 2020 – the attention of scientists, designers, engineers was paid, first of all, to the reduction in the costs of heat and power supply of buildings and structures (Harvey, 2009; Sandvall, Ahlgren & Ekvall, 2017; Hummel et al., 2021); green building construction, as to energy conservation and harmful emissions, the concept of an "active building" with a positive energy balance is rationally reasonable (Ksit & Majcherek, 2016; Eze, Ugulu, Egwunatum & Awodele, 2021) and innovative sustainable development-oriented construction, which means the life-sustaining or stable development without reducing the resources and capabilities of future generations (Lu, 2012; Kauskale, Geipele, Zeltins & Vanags, 2018). However, given a significant impact of construction on socio-economic development, the construction sector should be viewed as a complex subsystem in interaction with the environment (Zolfagharian, Nourbakhsh, Irizarry, Ressang & Masoud, 2012; Teriö and Honkanen, 2013; Enshassi, Kochendoerfer & Rizq, 2014).

Literature review

The studies of trends in the relationship between economic and environmental systems indicate the need to adapt the construction sector to dynamic innovative technologies. The concept of Industry 4.0, an innovative platform for environmental protection, is noteworthy. According to the authors, the development of Construction 4.0 using Industry 4.0 as an example will change the ways of interaction and the impact of the construction industry on the ecosystem (Sawhney, Riley & Irizarry, 2020). The researchers note that the prospects for sustainable development will be an effective way of using resources for future generations and they can help to reduce environmental degradation (Weißenberger, Jensch & Lang, 2014; Rostami, Khoshnava, Rostami & Lamit, 2015; Khoshnava, Rostami, Zin, Štreimikienë, Mardani & Ismail, 2020).

In recent scientific developments, scholars show great interest in the problems of the construction sector growth and its impact on the environment. According to some scientists, the fact of pressure of the construction sector on the environment is highly convincing (Yilmaz & Bakış, 2015; Razkenari, Fenner, Shojaei, Hakim & Kibert, 2020). In this context, the authors emphasize the importance of justifying the interaction of green building with the ecosystem (Kauškale & Riemenschneider, 2016; Olukoya & Atanda, 2020). If strategies of process integration are compared, it will help to make optimal decisions about integrating processes in construction networks outside a building site and about introducing changes in the ecosystem (Shen et al., 2008; Ruan, Ochieng, Price & Egbu, 2012; Arashpour, Wakefield, Blismas & Minas, 2015).

In spite of the availability of these research results, there are currently no scientific publications in which authors would try to empirically assess the relationship between the construction infrastructure development and sustainability of the ecosystem. Given the clear local concentration of construction (resource provision, construction and placement of finished construction products), it is essential to note the specifics of its development in the regional context.

In order to determine the regional specifics of the spatial and component structure of the integrated relationships between the construction sector and the ecological system, it is vital to pay attention to energy productivity. For example, in Australian regions, a group of scientists identified regional centres of effective strategies of energy consumption and defined patterns of energy productivity growth in the construction industry (Ma, Hosseini, Jiang, Martek & Mills, 2018). In addition, Australian scientists expanded their research on the benefits of reverse logistics (RL) in the construction industry. The study identified 12 barriers to the implementation of reverse logistics (RL), including the regulatory environment, unforeseen costs and non-recognition of the importance of the impact of the construction chain on the ecosystem (Rameezdeen, Chileshe, Hosseini & Lehmann, 2016).

In Ukraine and abroad, there is a scientific controversy about research on the dynamic relationship between the development of the construction sector and the growth of the regional economy. It is represented by three aspects: (1) a study of the role of the construction sector in socio-economic development of the country (Tatar, 2016; Kalinichenko & Sidorova, 2017; Fisunenko, 2018; Krysovatyy, Mokiy, Zvarych & Zvarych, 2018; Frolova, Zhadko, Ilyash, Yermak & Nosova, 2021); (2) a comprehensive study of the impact of the relationship between the construction industry and other industries on economic development of the region (Bogdan, 2012; Ilyash, Hrynkevych, Ilich, Kozlovskyi & Buhaichuk, 2020); (3) modelling the impact of the construction sector development on economic growth of the region (Momot, Filatova & Tofanyuk, 2011; Pynda, 2018; Mokiy & Antonyuk, 2019; Ilyash, Vasyltsiv, Lupak & Get'manskiy, 2021).

Despite the presented research on dynamic interrelations between the development of the subjects of the construction sector and the economy growth of regions (Mokiy, Ilyash, Pynda, Pikh & Tyurin, 2020), there are no studies on the role of intersystem relations in regional sectors of the economy and ecological system. In particular, a methodological approach to assessing the state and prospects of the construction system and its connection with the ecosystem in the regional context needs to be tested, the construction system structure requires formalization and components such as labour resources, industry productivity and its raw material and resource, financial and investment components have to be aggregated. Taking into account these components will help to qualitatively and quantitatively measure the indicators of integration of the spatial and sectoral subsystem of the construction sector and the ecosystem into a complex socio-economic macrosystem, as well as to assess the development of the construction and ecological system in the regional aspect. The whole range of outlined problems is presented in this scientific research.

Material and methods

Since the construction sector of the national economy consists of a number of functionally interconnected components (vertically and horizontally integrated), designed to ensure the implementation of common socio-economic goals and objectives, it can be considered to have all signs of systemicity.

A number of existing methods to determine the integrated indicators are accompanied by various complications or excessive subjectivism while justifying and determining the values of the weight components. The method of main components, deprived of these shortcomings which could be easily applied in studying of different in quality and content of hierarchical socio-economic systems. This methodological approach to the integrated assessment of the components of the construction sector involves the use of a multiplicative form of the integrated index, determines the corresponding dependencies of nonlinear relations often occuring in economic processes and phenomena than linear ones. One of its advantages should also be stated the possibility of simultaneous rationing and integrated assessment of indicators and their thresholds; the formalized justification of weights.

Baseline indicators for the calculation of integrated indexes in the construction sector are selected on the basis of expert analysis and displayed in Annex 1. Using the method of main components, the calculation of integrated indexes in the construction sector of the economy is carried out according to the following sequence of calculations:

$$I_t = \prod_{i=1}^{n} z_{it} * a_i; \ \sum_{i=1}^{n} a_i = 1; \ a_i \geq 0 \quad (1)$$

where:

I_t – integral indicator of system development dynamics,

z_{it} – normalized annual values of the indicators t,

$t = 1, T$,

a_i – weight annual coefficients,

$i = 1, n$.

The indicators of de-stimulants are converted into stimulants by normalization. The calculation of weight coefficients involves the design of a correlation matrix, the emphasizing of the main components, the calculation of load factor and the identification of the main components. The relationship between primary features and components is described by the following dependency (Kharazishvili & Dron, 2014):

$$y_t = \sum_{i=1}^{m} c_{it} G_t \quad (2)$$

where:

y_t – standardized values,

i – component with single variances within a year t,

$t = 1$,

T – years of the researched period; total variance is equal to the number of features m,

c_{it} – contribution of i-component in total variance set of indicators within a year t,

$i = 1$,

m – number of features.

Component G_t is defined as:

$$G_t = \sum_{i=1}^{n} d_{it} x_{it} \quad (3)$$

where:

d_{it} – load factors,

x_{it} – in-data,

$i = 1$,

n – number of features,

$t = 1$,

T – years of the researched period.

Weight coefficients a_i are calculated as:

$$a_i = \frac{c_i |d_i|}{\sum_{i=1}^{n} c_i |d_i|} \quad (4)$$

The methodical approach to the integral evaluation of system elements provides for the use of a multiplicative form of the integral index, which reflects nonlinear relationships, as well as normalization and integral evaluation of indicators, their threshold values; formalized justification of the weight factor (Sukhorukov & Kharazishvili, 2013).

Methodological approaches to identifying the interconnections of systems should be based on the targeted use of a set of interrelated methods, united by common principles to test the assumptions of determining the evaluation criteria related to particularities of the studied relations, as well as to determine the criteria of evaluating the accuracy of the results obtained for system-dynamic modeling of development of such systems of different kinds (socio-economic, technical, informational etc.) (Ilyash et al., 2020). A large number of links between systems are difficult to quantify, which limits modeling possibilities (O'Connor & McDermott, 2006; Krysovaty, 2018; Mokiy et al., 2019). The impact of the indices and factors of a complex system cannot be clearly predicted because of their variability and the transition of the system to a state of "disturbance" which requires a balance of the system. The works of Zadeh (1976), Kaufmann (1982), Zhukovin (1983), Borisov, Alekseev and Merkurieva (1989), Leonenkov (2005), Shtovba (2007) are devoted to this problem and related issues. Given the complexity of determining the relationship between complex systems, the formalization of such fuzzy, indefinite interconnections requires a description of the process of forming the complex system based on a fuzzy assessment of the state of the system using the fuzzy set method (O'Connor & McDermott, 2006; Mokiy, Pikh & Pynda, 2019; Pawlik & Shaposhnykov, 2019).

In terms of sets and state space, the notion of the set of the initial state and the set of the final (specified) state of a complex system is applied. In these terms, the stability of the subsystems is defined as a transition from an initial growth to a given growth and it occurs so that none of many factors exceed the allowable limits of a given change path of state of the complex system (Khodjayan, 2012).

Due to complexity, and in some cases impossibility to take a quantitative measurement, one of the atypical research methods, in particular the fuzzy set method (fuzzy logic), was used to identify the level of impact of the components of the construction sector on the environment. The tool for studying fuzzy models was the MATLAB package, in which the formation of a fuzzy logic classification and derivation system was carried out using the Fuzzy Logic Toolbox module.

Methodological approaches to identifying the dynamic characteristics of interconnections between systems and the complex system should take into consideration the existence of direct and indirectly hidden (according to Fritjof Capra) connections between the components (Fridtjof, 2004) and the dependence of the effective indicators of the development dynamics on factors of various degrees of influence (Antonyuk, 2016).

Let's consider the dynamics of the development of a complex system on the basis of fuzzy sets. In the general case, the definition of a set of S would have the form:

$$S = \mu_i(x) \tag{5}$$

where:

$\mu_i(x)$ – function of the assessment rating of the situation with the i-parameter which reflects factors to determine belonging to fuzzy sets (Gil, 2001).

The automation of the fuzzy simulation process of estimating the state of a complex system is done using a software product MATLAB and package Fuzzy Logic Toolbox. The components of complex system are characterized by a set of n indicators: $X = (x_i)$, $i = \overline{1, n}$ where is the number of indicators.

Results and discussion

The approbation of the described methodological approach is based on the example of the spatial-sector subsystem of construction in the complex socio-economic macro system (Pynda, 2018). The very subsystem of the high-spatial sector includes functionally interconnected subsystems (vertically and vertically integrated) to achieve socio-economic goals and solve problems.

The assessment of the state and prospects of the development of the construction system and its relationship with the country's ecosystem requires the formalization of its structure. System features of the functioning and the presence of problems connected with the development of the construction system allow us to aggregate such important components as (Annex 2): (1) labour-resource (personnel and social productivity) (x_1); (2) productive component (results of the functioning of the construction system are reflected by indicators of commissioning of housing) (x_2); (3) raw material resource component (state of the system and related branch subsystems of the construction industry, reflected by indicators of the volumes of extracted building raw materials and building materials production) (x_3); (4) finance and investment component (financial elements of the construction system (enterprises) and sector investment capacity) (x_4); (5) foreign trade (volumes of import-export operations in the construction subsystem) (x_5).

The following conditions are important for displaying the components listed by the relevant indicators: (1) qualitative and quantitative measurement of indicators; (2) report presentation to the official statistics; (3) opportunity to assess the development of the construction system at the macro level and meso levels of the management hierarchy.

Formalization of the set of indicators provides a systematic approach to diagnosis, reduces the risk of overloading and "clogging" of unnecessary data (Klimenko, Feshchenko & Voznyuk, 2010). For each of the components there is a different degree of impact on the development of construction, and, moreover, in the regions, the indicators reflect the specificity of the subsystem of the lower (second) level of the system hierarchy. Thus, the labour-resource component is characterized by the greatest values of integrated indices, namely, the most significant influence on the development of the construction subsystem in the regions; the largest values are observed in Dnipropetrovsk (integrated index is 0.565), Zaporizhya (0.544), Rivne (0.582), Sumy (0.639), Kharkiv (0.616) and Chernivtsi (0.672) regions.

The integral indicators for the development of major components of the construction process are calculated in the dynamics of the years 2013 and 2018, and the environmental index, taking into account its relative stability, for 2018 (Annex 2).

Thus, for each component we define a subset of indicators $X_r = (x_{ir})$, $i = 1.5$;

r = 1.28. Given that the study took place from 2013 to 2018, the subset of the indicators has the form $X_{rt} = (x_{irt})$, where x – is a complex construction parameter in the region, i = 1.5 and t = 1.6 (Marushchak, 2014).

Therewith:

$$\forall i = \overline{1,5}; X_i \subset X; \forall t = \overline{1,5}; X_{it} \subset X_r \quad (6)$$

The complete set of levels of the construction system development in the i^{th} region consists of five fuzzy subsets of the species: Extremely Low (EL), Low (L), Medium (M), High (H), Very High (VH). Subsets of this type are given as linguistic changes in accordance with the formed term-sets. It is defined that five components form the term-set of the linguistic variable "Level of development of the construction system" in the region. To form a fuzzy set, we used the Mamdani algorithm, which describes several successive steps, each receiving the input values obtained in the previous step. At the "input" and "output" arrive the quantitative values. In the intermediate stages, the fuzzy logic apparatus is used for fuzzy set theory (Shtovba, 2007).

The rules consist of conditions and conclusions which, in their turn, are vague statements, and include the linguistic variable and the term represented by fuzzy terms. When forming a rule base, each condition is given a weighting factor (Ri) or a degree of certainty about the truth of the result (prerequisites) {EL – «Extremely Low»), L – «Low»; M – «Medium»; H – «High»; VH – «Very High» level}, i = 1.5 (Fig. 1). It is assumed that the weight factor is equal to 1. The linguistic variables, written in condition, are called incoming and outgoing, the values of which are calculated by setting the range of changes with the corresponding gradation (Fig. 2).

Fuzzy output of the studied results is based on the formation of sets. At the phasing stage, the values of the incoming variables are converted to the values of linguistic type variables with the help of a membership function of a fuzzy number. At the stage of elaborating conditions, solutions and defazification,

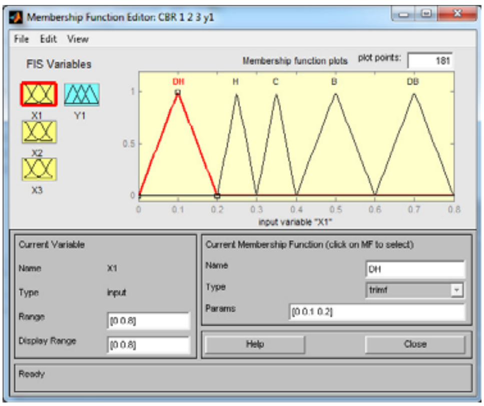

FIGURE 1. Graphical representation of the x_1 variable through the triangular membership function using Membership Function Editor

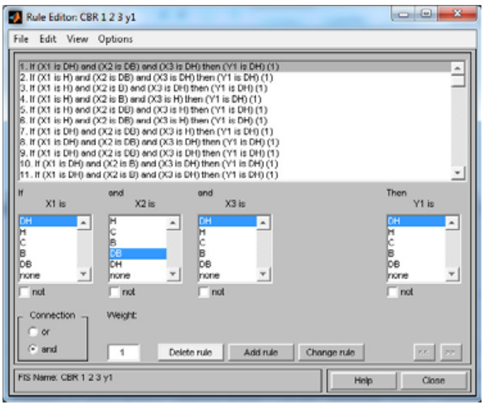

FIGURE. 2. Fuzzy Mamdani knowledge base in Rule Editor

there is a shift from fuzzy values to the specified parameters. A fuzzyfication stage of incoming variables leads to fuzziness (Leonenkov, 2005). To the “input” arrive the base of rules and an array of input data $X = (x_i)$ that contains values of all the “incoming” (x_i) variables $i = \overline{1, 5}$ and of the “outgoing” (y) variable. The goal of the stage is to obtain truth values for all conditions from the rule base. The value of the weighting factor of the rules is taken equal to one.

The accuracy of the evaluation depends on the completeness of the knowledge base. The achievement of the flexibility of the process of assessing the development of the subsystem in construction is achieved through the task of key decision-making rules, the logical conclusion for each of these rules is formed at the defuzzification, which turns fu ozzuio ccy data from the output block of solutions to a clear value (Babets, 2013).

While setting conditions, the minimum value of the all true prerequisites is searched

$$a = \min\{x_i\} \tag{7}$$

where:
$i = 1$,
n – prerequisites numbers.

Thus, the purpose of this stage is to obtain a set of “activated” membership functions

$$\mu_i'(x) = \min\{x\} = \{d_i\,, \mu_i\,(x)\} \tag{8}$$

where:
$\mu_i'(x)$ – “activated” membership function,
$\mu_i(x)$ – term membership function,
d_i – degree of truth of i-prerequisite.

The purpose of defuzzification is to obtain quantitative values for each of the “outgoing” linguistic variables, using the i “source” of variable and the set X_i, which refers to it and takes into consideration the total value of the outgoing variable.

$$y_i = \frac{\int_{\min}^{\max} x \cdot \mu_i\,(x)\,\mathrm{d}x}{\int_{\min}^{\max} \mu_i\,(x)\,\mathrm{d}x} \tag{9}$$

where:
$\mu_i(x)$ – membership function to the corresponding fuzzy set X_i,
min, max – limits of the entirety fuzzy variables,
y_t – result of defuzzification (Kaufmann, 1982).

The simulation of the optimal development of the construction system is done on the basis of the objective function:

$$f_j = \max_t \left\{ \max_i \left\{ \sup_{x \in X_i} \left(\min\{\mu_{x_i}(x), \mu_{x_i}(x)\} \right) \right\} \right\} \tag{10}$$

where:
X_i – values range of i^{th} parameter $\left(i = \overline{1, 5}\right)$,
$\mu_{x_i t}$ – functions of the membership of fuzzy subsets of the main elements of the construction subsystem of the region, where $i = \overline{1, 5}$; $i = \overline{1, 6}$.

According to the obtained results, the surfaces of their predicted relationship values are formed. The closest connection can be traced in the following combinations (Fig. 3). The revealed interconnections of the construction system with the ecosystem are the basis for their optimization (Fig. 3, the table).

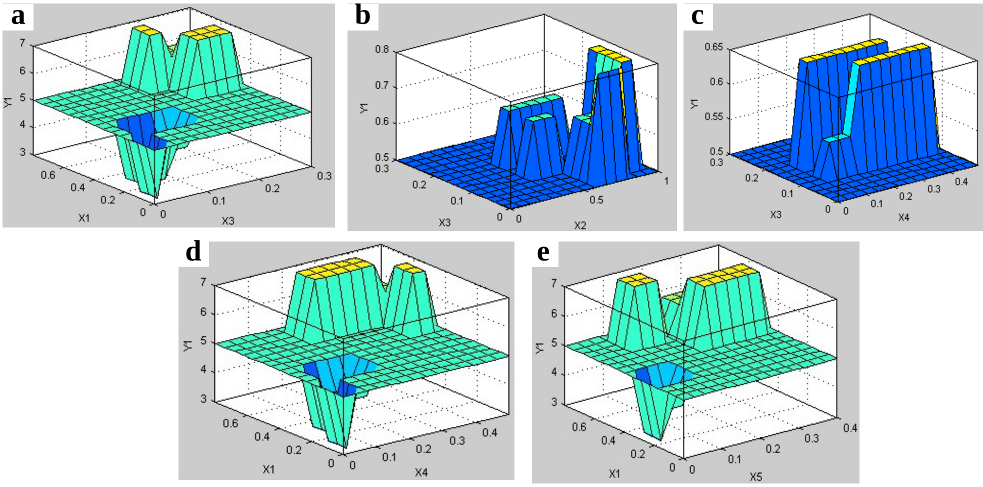

FIGURE 3. Fragment of three-dimensional surfaces of the predicted values of interconnections of the construction sector and the environment: a – interconnection between labour-resource (x_1), interconnection between raw material resource (x_3), components and environment (Y); b – interconnection between productive (x_2), raw material resource (x_3) components and environment (Y); c – interconnection between raw material resource (x_3), finance and investment (x_4) components and environment (Y); d – interconnection between labour-resource (x_1), finance and investment (x_4) components and environment (Y); e – interconnection between labour-resource (x_1), foreign trade (x_5) components and environment (Y)

TABLE. Fragment of the interconnections model between the construction sector components and the environment (Y)

Integral indicator of					Ecological index (Y)	Level
labour--resource component (x_1)	productive component (x_2)	raw material resource component (x_3)	finance and investment component (x_4)	foreign economic component (x_5)		
0.101	0.717	0.0669			0.2	EL
0.111	0.681	0.0163			0.2	
0.101	0.717	0.0669			0.2	
0.246	0.717	0.0669			0.3	
0.255	0.693	0.0596			0.3	
0.246	0.5	0.132			0.55	L
0.467	0.38			0.19	0.65	M
	0.5	0.179	0.25		0.65	
	0.524	0.168	0.334		0.65	
	0.596	0.175	0.304		0.65	
	0.741	0.175	0.304		0.65	
	0.753	0.0849	0.304		0.65	
	0.753	0.168	0.334		0.65	
0.602	0.38			0.19	0.8	H
0.699	0.452		0.232		0.8	

H – «High»; M – «Medium»; L – «Low»; EL – «Extremely Low» level.

The obtained results (Fig. 3, the table) reflect the relationship between the construction system and the environment over the 2013–2018 period.

Thus, the scientific hypothesis of the relationship between building systems and the environment is confirmed, which can be applied when determining such rationally feasible parameters, as:

1. A significant effect on the high level of the environmental index (0.8) is observed through the following combination:
   – when x_1, x_2, $x_5 \rightarrow Y$ – an integral indicator of the labour and resource component equals 0.602, that is true only for Sumy, Kharkiv and Chernivtsi regions; an integral indicator of the productive component at 0.38 is traced only in Ivano-Frankivsk, Kyiv, Lviv and Odesa regions.; An integral index of the foreign economic component at the level of 0.19 takes place only in Kherson region.
2. The average level of the environmental index (0.65) is influenced by the following optimal combinations:
   – when x_1, x_2, $x_5 \rightarrow Y$ – an integral indicator of the labour and resource component at the level of 0.467 is observed in Dnipropetrovsk, Transcarpathian, Zaporizhia, Mykolaiv, Poltava, Rivne, Sumy, Kharkiv, Cherkasy and Chernivtsi regions; the value of an integral indicator of the productive component is 0.38; an integral index of the foreign economic component at the level of 0.19, respectively;
   – when x_2, x_3, $x_4 \rightarrow Y$ – an integral indicator of the productive component at the level of 0.5 is peculiar only to Kyiv region; the value of an Integral indicator of the raw material component 0.179 is also observed only in Kyiv region; an integral index of the financial and investment component 0.25 is observed only in Mykolaiv and Ternopil regions.

According to the simulation results, the current state of the construction sector in most regions of Ukraine shows the relationship of its components with the lowest level of the environmental index, which confirms the hypothesis of a significant negative impact of construction on the country’s ecosystem.

The results of the study confirm the different levels of impact (described by different diagrams) of the development components of construction sector on the environment. The obtained model will enable predicting the impact of components of the construction sector on the environment according to the optimal values calculated in terms of regions of Ukraine, taking into account their specificity and importance, based on the results of the principal component method.

Conclusions

The construction system development is closely related to the ecosystem and requires constant adaptation of the construction sector to rapid changes in scientific and technological progress in order to reduce the negative impact on the environment. However, given the long payback period, high cost and multi-component nature of construction products, as well as the connection of construction with other sectors of the economy, the ability to innovate in the construction sector depends on the intersystem relations of the regional economy and the environment. Due to the use of fuzzy logic methods to study the relationship between the building system and the ecosystem, this research developed a methodological approach to the integral assessment of system elements based on the creation of a multiplicative form of the integral index that reflects nonlinear connections with the environment.

The approbation of the used methodological approach is based on the example of the spatial and sector subsystem of construction in a complex socio-economic macrosystem. The results presuppose the formalization of its structure and aggregation of five components (labour, productive, raw material and resource, financial and investment components, as well as foreign trade) and the study of the development of the construction system at the regional level. Based on the results, the labour component has a significant impact on the development of the construction subsystem in the regions; the largest values of integral indices are observed in Dnipropetrovsk (0.565), Zaporizhzhia (0.544), Rivne (0.582), Sumy (0.639), Kharkiv (0.616) and Chernivtsi (0.672) regions.

The simulation of the optimal development of the building system in the macrosystem is carried out based on the objective function and defuzzification. The results showed the existing three types of relationships between the construction sector and the ecosystem: (1) between labour resources and the components of raw materials and the environment; (2) between the productive component and the components of raw materials and the environment; (3) between the financial and investment component and the components of raw materials and the environment. Consequently, the study helped to build models of the relationships between the components of the construction sector and the environment and calculate their predicted values. Due to the low level of initial results in the regions of Ukraine, the target parameter (the environmental indicator) had the value above the average level (3%).

This study provides a selection of optimal models for studying the relationship between the construction sector and its components with the lowest level of the environmental index in the country's regions. In addition, the study is a guide for further research to discuss ways of reducing the negative impact of construction on the ecosystem.

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ANNEX 1. Resource components indicators of the construction sector of the economy (own elaboration)

Labour component (x_1)	the number of people employed in construction per 1000 people of population level; average monthly nominal wages of construction workers; share in the structure of household cash expenditures on housing construction; the availability index of residential real estate.
Production component (x_2)	the volume of construction work carried out on residential buildings; the volume of construction work carried out on non-residential buildings; the volume of construction work carried out in the construction of engineering structures; commissioning of housing in cities per 1000 inhabitants; commissioning of apartments per 10,000 people; commissioning of housing in rural areas per 1000 inhabitants.
Raw material resources component (x_3)	production of non-refractory ceramic building bricks per 1000 people; production of blocks and bricks from cement, concrete or artificial stone for construction per 10,000 people; production of prefabricated structural elements for construction from cement, concrete or artificial stone per 1000 people; production of concrete solutions, ready for use per 1000 people; extraction of natural sands per 1000 people; mining pebbles, gravel, road metal and crushed stone per 1000 people; production of wooden windows, doors, their frames and thresholds per 10,000 people.
Financial and investment component (x_4)	Financial report (balance) of construction companies for 1 person; Profitability of operating activities of construction enterprises; The share of capital investment in construction; The share of capital investment in production of building materials.
Foreign economic component (x_5)	Exportation of stone, gypsum and cement products per 1000 people; Importation of stone, gypsum and cement products per 1000 people; Construction services export per 1000 people; Construction services import per 1000 people.

ANNEX 2. Spatial-component structure dynamics of integral indicators of subsystem development in construction and environment, 2013–2018 (own calculations and elaboration)

Region	Integral indicators of the development of the main elements in construction sector										Ecological index
	x_1		x_2		x_3		x_4		x_5		Y_1
	2013	2018	2013	2018	2013	2018	2013	2018	2013	2018	2018
Vinnytsia	0.469	0.397	0.159	0.262	0.108	0.018	0.095	0.092	0.025	0.012	0.856
Volyn	0.417	0.410	0.131	0.308	0.022	0.034	0.083	0.061	0.005	0.006	0.902
Dnipropetrovsk	0.440	0.565	0.105	0.185	0.071	0.047	0.049	0.110	0.004	0.002	0.361
Donetsk	0.504	0.290	0.101	0.022	0.052	0.004	0.032	0.100	0.035	0.032	0.467
Zhytomyr	0.452	0.417	0.109	0.146	0.147	0.109	0.142	0.085	0.004	0.071	0.883
Transcarpathian	0.558	0.499	0.124	0.200	0.024	0.021	0.074	0.061	0.012	0.036	0.853
Zaporizhia	0.522	0.544	0.082	0.081	0.048	0.035	0.011	0.010	0.012	0.017	0.844
Ivano-Frankivsk	0.089	0.061	0.247	0.413	0.027	0.026	0.111	0.158	0.064	0.019	0.785
Kyiv	0.492	0.450	0.420	0.828	0.141	0.212	0.023	0.048	0.007	0.015	0.842
Kirovohrad	0.522	0.451	0.028	0.281	0.058	0.048	0.034	0.085	0.009	0.005	0.875
Luhansk	0.533	0.372	0.070	0.020	0.015	0.001	0.047	0.019	0.012	0.042	0.811
Lviv	0.411	0.444	0.229	0.457	0.138	0.173	0.034	0.177	0.005	0.011	0.766
Mykolaiv	0.438	0.484	0.126	0.180	0.102	0.063	0.027	0.296	0.005	0.028	0.769
Odessa	0.434	0.365	0.294	0.420	0.017	0.010	0.015	0.185	0.005	0.005	0.838
Poltava	0.552	0.496	0.182	0.285	0.074	0.039	0.037	0.083	0.001	0.009	0.966
Rivne	0.528	0.582	0.143	0.283	0.039	0.034	0.028	0.138	0.008	0.012	0.870
Sumy	0.573	0.639	0.122	0.155	0.012	0.013	0.040	0.051	0.006	0.010	0.803
Ternopil	0.438	0.427	0.214	0.348	0.053	0.052	0.081	0.269	0.009	0.007	0.871
Kharkiv	0.466	0.616	0.159	0.232	0.028	0.028	0.039	0.204	0.036	0.020	0.863
Kherson	0.400	0.346	0.131	0.105	0.018	0.008	0.121	0.104	0.206	0.319	0.889
Khmelnytskyi	0.477	0.415	0.204	0.379	0.081	0.102	0.116	0.100	0.003	0.012	0.915
Cherkasy	0.515	0.474	0.134	0.127	0.068	0.030	0.017	0.045	0.031	0.101	0.914
Chernivtsi	0.558	0.672	0.226	0.313	0.024	0.030	0.074	0.039	0.045	0.035	0.902
Chernihiv	0.494	0.432	0.129	0.181	0.015	0.008	0.125	0.067	0.001	0.002	0.843

Summary

Characteristics of interconnections of construction sector and environment: regional study of Ukraine. The proposed modelling of the relationship between the spatial and component structure of the construction industry development and the environment helped to obtain combinations of high and medium levels of the impact of integral indicators of labour, productive and foreign economic components of the construction sector on the environmental index of the region. The high level of adaptability of the models used for the period 2013–2018 confirms the relationship between the development of the construction sector in most regions of Ukraine and the lowest level of the ecological index. This proves the scientific hypothesis about the negative impact of construction on the country's ecosystem. The study indicates that the dynamic characteristics of the relationship between the building system and the environment should take into account the existence of direct and indirect or even "hidden" relationships between the components. The scientific value of the study consists in using models of fuzzy sets to assess the relationship between the construction system and the ecosystem based on defuzzification, which preserves the flexibility of the process of assessing the development of subsystems in construction and making decisions as to reducing the negative environmental impact in regions.

Authors' address:
Anatoliy Mokiy
(https://orcid.org/0000-0001-8455-1421)
Dolishniy Institute of Regional Research of National academy of Sciences of Ukraine
Kozelnytska St. 4, 79026 Lviv
Ukraine
e-mail: amokiy320@ukr.net

Yuriy Pynda
(https://orcid.org/0000-0002-1431-2318)
Lviv University of Business and Law
Kulparkivska St. 99, 79021 Lviv
Ukraine
e-mail: yuriy_p1@ukr.net

Olha Ilyash – corresponding author
(https://orcid.org/0000-0002-7882-3942)
International University of Finance
National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute"
Prospekt Peremohy 37, 03056 Kyiv
Ukraine
e-mail: oliai@meta.ua

Mariia Pikh
(https://orcid.org/0000-0003-4461-0364)
National University of Food Technologies
Lviv State College of Food and Processing Industry
Pulia St. 42, 79060 Lviv
Ukraine
e-mail: pmariyka@gmail.com

Rostyslav Pynda
(https://orcid.org/0000-0001-5326-9343)
Lviv University of Business and Law
Kulparkivska St. 99, 79021 Lviv
Ukraine
e-mail: rostyslav_p1@ukr.net