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## TECHNOLOGY FOR EVALUATING AND SELECTING COWORKING SPACES ACCORDING TO CLIENTS' TARGET NEEDS

*The main goal of this study is to develop a technology for evaluating and selecting coworking spaces (CS) according to the target needs of clients. For this purpose, the following were developed: a fuzzy model for evaluating coworking; a model for aggregating the output data of the fuzzy model for evaluating coworking and the target needs of clients; a validation of the study based on 5 coworking spaces is presented. The research is based on the apparatus of fuzzy sets, which allows one to increase the degree of validity of decisions. The input data are given in estimation intervals that consider all possible scenarios. An intellectual analysis of knowledge is used to process input information, the subjectivity of experts is revealed, and the final assessment is presented in quantitative form. The value of the model is that it allows one to obtain a quantitative assessment of CS from input fuzzy expert data, and the assessment procedure for experts is simple and natural. The model considers the users' goals regarding an environment that increases work productivity, namely: environmental goals, social goals, and innovation goals. At the model's output, we have an initial quantitative assessment and a ranking series of CS. The research that was conducted contributes to the development of CS, increasing its efficiency and compliance with market needs. It is also useful for freelancers, startup teams, and small businesses, who receive a tool for choosing a space that meets their needs in terms of location, budget, and conditions.*

**Keywords:** multi-criteria evaluation of alternatives, fuzzy sets, fuzzy logic, coworking spaces, expert evaluation, decision maker (DM).

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### Introduction

With the spread of remote work, startups, and freelancing, the demand for coworking spaces (CS) has increased significantly. This necessitates a systematic approach to their evaluation and selection. CS customers have different goals: access to technological equipment, convenient location, and a conducive environment for teamwork or individual productivity. Therefore, it is important to create technology that takes these needs into account. CS evaluation includes subjective factors (e.g., comfort or interior style) that are difficult to quantify. Fuzzy logic-based technologies allow for efficient work with such data (Rudnitskii et al., 2021). Moreover, the growing number of CSs forces owners to look for ways to improve their services. The development of evaluation technology will help both customers and operators better understand the key factors for success. The use of modern technologies, such as data analysis and fuzzy logic models (Arun et al., 2024), ensures objectivity of assessment and adaptability to changing customer needs. Choosing the optimal CS contributes to the efficient use of resources, increased employee productivity, and customer satisfaction, which is important for small and medium-sized businesses.

When choosing a coworking space, numerous criteria are taken into account, such as price, technical equipment, accessibility, aesthetics, etc. Fuzzy logic allows you to effectively integrate these heterogeneous parameters into a single model (Fast, & Jansson, 2024). The fuzzy set theory allows you to process fuzzy, blurred data, representing them in the form of a degree of belonging to certain sets (for example, "high level of comfort" or "moderate cost"). It also helps to avoid hard limits (for example, "price up to \$ 100"), which is a drawback of traditional evaluation models. In addition, fuzzy logic allows you to model the real decision-making process of a client, where certain criteria may partially satisfy needs. For example, a coworking space can be "quite convenient" and "almost affordable", which is taken into account in the overall assessment. Fuzzy logic also allows for more accurate and well-founded evaluation results, reducing the risk of erroneous decisions that may arise due to overly generalized or strict criteria. The use of fuzzy set theory is an advanced approach that contributes to the development of innovative analysis methods and provides effective, flexible, and realistic modeling of the process of evaluating and selecting coworking spaces, which meets modern challenges and needs.

Modern research places coworking spaces within a broader category of "new workspaces" (Mariotti et al., 2024), which have emerged as a result of digitalization, although they are not limited to it. Coworking spaces share similar features with spaces such as Fab labs, Makerspaces, Hackerspaces, Living labs, Innovation hubs, but at the same time have their unique characteristics (Micek, Baycan, & Lange, 2024; Tomaz, & Tabrizi, 2024). The beginning of the coworking movement is associated with the creation of The San Francisco Coworking Space in 2005, which became a model for shared workspaces

in the "dot-com zone" (De Peuter, Cohen, & Saraco, 2017). This concept gained considerable popularity worldwide, especially before the COVID-19 pandemic in 2020, which significantly affected the industry due to quarantines and safety measures. The long-term consequences of the pandemic are still being analyzed, including its impact on new workspaces (Mariotti et al., 2022). This demonstrates the dynamism of the market, its vulnerability to external factors, and the need for new approaches to evaluating and managing coworking spaces.

Our study is also seen as a tool that allows entrepreneurs, local government representatives, and other stakeholders to participate in decision-making on the opening of new coworking spaces to promote economic, business, and social transformation. In the context of business decision support systems, many important works can be highlighted. For example: (Piwowski, & Nermend, 2022) examines the challenges of applying multi-criteria methods in complex business processes; (Yalcin, Kilic, & Delen, 2022) focuses on the use of business analytics and multi-criteria modeling for effective decision-making by enterprises; (Ceballos et al., 2021) presents a strategy that combines data and business rules based on multi-criteria analysis; (Wu et al., 2022) develops an integrated multi-criteria model for selecting a socially responsible investment portfolio; in the works (Buchnik, & Frenkel, 2023; Lin et al., 2022) a hybrid assessment model was created for the analysis of smart office buildings.

CS also plays an important role in supporting refugees affected by the war in Ukraine, providing them with workspace, social integration, and access to necessary resources. Coworking spaces often organize training, seminars, and workshops (Di Marino et al., 2023), helping refugees improve their professional skills, learn new technologies, or adapt to the local labor market. Coworking spaces often have resources for business development, mentoring, and legal advice, which helps refugees start their initiatives or businesses even in new conditions (Hendriks et al., 2024). The working environment provided by coworking spaces helps reduce stress and feelings of isolation, promoting psychological recovery (Figueiredo, Dierks, & Ferreira, 2024). However, there is no mathematically based research on the evaluation and selection of coworking spaces taking into account the target needs of clients.

The main goal of this study is to develop a technology for evaluating and selecting coworking spaces according to the target needs of clients. To do this, it is necessary to develop: a fuzzy model for evaluating coworking; a model for aggregating the output data of the fuzzy model for evaluating coworking and target needs of clients; a system of criteria for evaluating coworking spaces and a fuzzy knowledge base for evaluating coworking spaces according to the target needs of DM.

From the above, we can formulate the scientific hypothesis of this study as follows. If the selected coworking space satisfies all the needs of the employee, ensuring his development, then we can say about the high assessment of coworking, obtained on the basis of the constructed fuzzy model that takes into account the target needs of employees.

The research is based on the fuzzy set apparatus, which allows to increase the degree of validity of decisions. Input data is given in assessment intervals that take into account all possible scenarios. Intellectual knowledge analysis is used to process input information and reveal the subjectivity of experts, and the final assessment is presented in quantitative form. The value of the model is that it allows us to obtain a quantitative assessment of coworking spaces based on input fuzzy expert data, and the assessment procedure for experts is simple and natural. Input data is processed by appropriate fuzzy models, revealing the subjectivity of experts, and setting the parameters of models and target needs of clients makes it impossible for system analysts or experts to have a subjective influence on the assessment process and the final result of choosing a coworking space by clients. At the output of the model, we have an initial quantitative assessment and a ranking series of coworking spaces for selection by clients, taking into account their target needs.

The conducted research contributes to the development of coworking spaces, increasing their efficiency and compliance with market needs. It is also useful for freelancers, startup teams, and small businesses, who receive a tool for choosing a space that meets their needs in terms of location, budget, and conditions. It also helps coworking owners understand customer needs, optimize services, and increase competitiveness. Consulting companies can use the model to develop strategies for creating and managing coworking spaces. Therefore, the research contributes to the development of coworking spaces, increasing their efficiency and compliance with market needs.

The research is organized as follows: in section 2, a formal statement of the problem is formulated, a fuzzy model for evaluating coworking is described; a model for aggregating the output data of the fuzzy model for evaluating coworking spaces and target customer needs; a system of criteria for evaluating coworking spaces, as well as a fuzzy knowledge base for evaluating coworking spaces according to DM target needs. Section 3 presents the validation of the study based on 5 coworking spaces. Section 4 analyzes and discusses the results of the study, presents scientific and practical conclusions, and identifies areas for further research.

### 1. Main definitions and results

Formally, the technology of evaluation and selection of coworking spaces according to the target needs of clients can be presented as follows:

$$\{C, K_E, K_S, K_I, M_C, G_E, G_S, G_I, M_A | f\}. \tag{1}$$

Where:  $C = \{c_1; c_2; \dots; c_n\}$  – a set of CS in a certain region for evaluation and selection by customers;  $K_E$  – a set of evaluation criteria for the coworking facility itself, this is its office infrastructure, location, and environmental policy;  $K_S$  – a set of evaluation criteria for coworking entities, social atmosphere, and knowledge exchange;  $K_I$  – a set of criteria for evaluating innovative potential, this is new funding opportunities, new opportunities for business, improving a higher level of productivity;  $M_C$  – a fuzzy coworking evaluation model;  $G_E$  – ecological goal (importance of the object);  $G_S$  – social goal (importance of the subject);  $G_I$  – innovative goal (interaction of subjects and business);  $M_A$  – a model for aggregating output data of a fuzzy  $M_C$  coworking evaluation model and goal user needs. As a result, we obtain the output score  $f$  based on which a ranking series of coworking spaces are built for customers to choose from, considering their needs.

Since our task is in the area of decision-making support with the help of expert evaluation, we will introduce the following management subjects: a system analyst is a person who configures and manages the evaluation process; an expert forms a set of evaluation criteria for the relevant types of coworking spaces, selects a set of alternative CS and evaluates them; a decision-maker (DM) is a user (customer) who makes a decision regarding the choice of a coworking space, he sets his own target needs and, if necessary, enters additional parameters for the choice.

We will illustrate the technology of evaluation and selection of CS following the goal needs of users in the form of a structural diagram (Fig. 1).

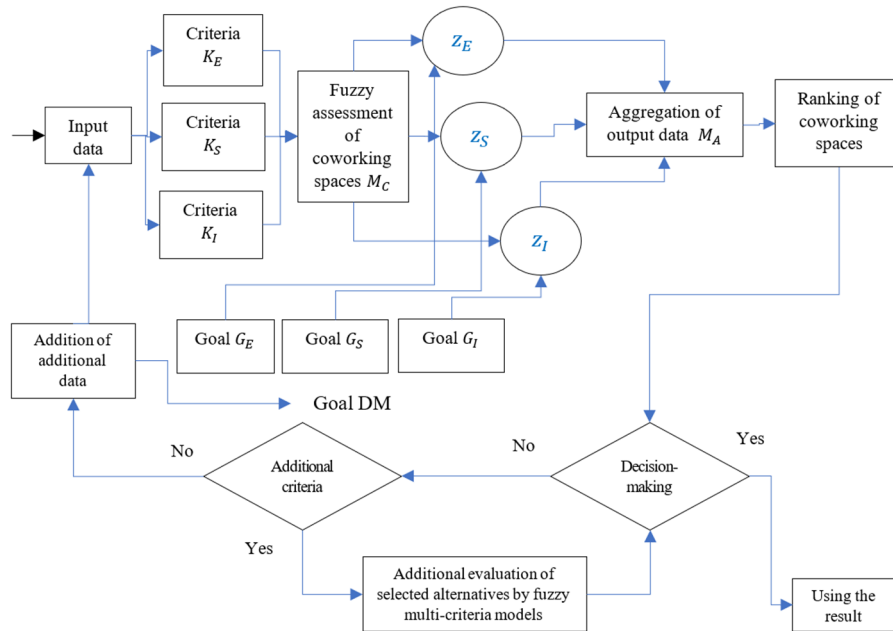


Fig. 1. Structural diagram of the technology evaluation and selection of CS

Figure 1 reflects the structural diagram of CS evaluation, based on the developed models, available input data, and the goals of DM. After evaluating and deriving a ranking series of CS, a decision is made about the choice. If the solution does not satisfy the DM, it is possible to involve additional criteria for the evaluation and use fuzzy models (Kelemen, Gavurova, & Polishchuk, 2022; Polishchuk, 2019). Another option is to review the DM's goal needs, change the parameters of the evaluation models, or involve new data by the system analyst. At the output for choosing a DM, there will be a series of coworking spaces and their aggregated normalized evaluations to increase the degree of validity of decisions.

The mathematical model for evaluating and selecting coworking spaces following the goal needs of customers will be presented in the form of two sub models: fuzzy evaluation of coworking spaces according to the proposed set of criteria and data aggregation using the goal needs of customers.

$M_C$  is proposed – a fuzzy coworking evaluation model, which is based on the expert's opinions, in a certain range of coworking quality values according to certain indicators. At the first stage, the expert analyses a set of coworking spaces  $C$ , using his own experience and expresses his reasoning according to  $K_E, K_S, K_I$  sets of evaluation criteria.

In practice, people express their thoughts not in clear discrete values, but in intervals. For example: "the rating of coworking according to some criterion should be close to a number", or "the rating of coworking according to a certain criterion will most likely lie within certain limits", etc. Therefore, it is advisable to set the rating  $x$  according to each criterion in some interval of numbers  $x \in [a_0; b_0]$ . Let the expert express his opinion on some criterion according to one of the linguistic statements  $CL = \{A; B; C; D\}$ , where:  $A = \{\text{coworking assessment according to a certain criterion is within the range from } a_1 \text{ to } b_1\}$ ;  $B = \{\text{the evaluation of coworking according to a certain criterion is close to the number } b_1\}$ ;  $C = \{\text{the evaluation of coworking according to a certain criterion is not greater than the number } b_1\}$ ;  $D = \{\text{coworking assessment according to a certain criterion is not less than the number } b_1\}$ ,  $\{a_1; b_1\} \in [a_0; b_0]$ . The set of linguistic statements is open and, if necessary, the system analyst can supplement or change it.

Next, all fuzzy statements are described using fuzzy set theory and membership functions.

Statement  $A = \{\text{coworking assessment according to a certain criterion is within the range from } a_1 \text{ to } b_1\}$  is treated as a fuzzy set and is formalized using a trapezoidal membership function (Kelemen, Gavurova, & Polishchuk, 2022):

$$\mu_A(x) = \begin{cases} 0, & x \leq a_0; \\ \frac{x-a_0}{a_1-a_0}, & a_0 \leq x < a_1; \\ 1, & a_1 \leq x < b_1; \\ \frac{b_0-x}{b_0-b_1}, & b_1 \leq x < b_0; \\ 0, & x \geq b_0. \end{cases} \quad (2)$$

The following linguistic statement  $B = \{\text{the evaluation of coworking according to a certain criterion is close to the number } b_1\}$ , is formalized using a triangular membership function (Kelemen, Gavurova, & Polishchuk, 2022):

$$\mu_B(x) = \begin{cases} 0, & x \leq a_0; \\ \frac{x-a_0}{b_1-a_0}, & a_0 < x \leq b_1; \\ \frac{b_0-x}{b_0-b_1}, & b_1 < x < b_0; \\ 0, & x \geq b_0. \end{cases} \quad (3)$$

Statement C = {the evaluation of coworking according to a certain criterion is not greater than the number  $b_1$ }, is characterized in fuzzy sets by a Z-like type of membership function (Kelemen, Gavurova, & Polishchuk, 2022):

$$\mu_C(x) = \begin{cases} 1, & 0 < x \leq b_1; \\ \frac{b_0-x}{b_0-b_1}, & b_1 < x \leq b_0; \\ 0, & x > b_0. \end{cases} \tag{4}$$

A final linguistic consideration D = {coworking assessment according to a certain criterion is not less than the number  $b_1$ } represents the uncertainties of the S-shaped membership function type (Kelemen, Gavurova, & Polishchuk, 2022):

$$\mu_D(x) = \begin{cases} 0, & x \leq a_0; \\ \frac{x-a_0}{b_1-a_0}, & a_0 < x \leq b_1; \\ 1, & x > b_1. \end{cases} \tag{5}$$

Therefore, the statements of the system analyst regarding coworking indicators will not represent discrete values, but intervals of values, according to the selected rule CL = {A; B; C; D}.

In the next stage, we will move from fuzzy evaluation intervals to one-point evaluation. For this, let DM set the weighting coefficients for each evaluation criterion  $w_{kj}, k = \{E; S; I\}; j = \overline{1, \bar{k}_k}$ , for example from the interval [1;10]. Next, their normalization is carried out within the limits of the appropriate set of criteria  $K_E, K_S, K_I$ :

$$\alpha_{kj} = \frac{w_{kj}}{\sum_{j=1}^{k_k} w_{kj}}, k = \{E; S; I\}; \alpha_{kj} \in [0; 1]. \tag{6}$$

For data fuzzification, we will find a weighted sum to determine the aggregated expert opinion within one set of evaluation criteria  $K_E, K_S, K_I$ :

$$\delta_{ki}(x) = \sum_{j=1}^{k_k} \mu_{CL, k_j}^i(x) \cdot \alpha_{kj}, k = \{E; S; I\}, i = \overline{1, \bar{n}}. \tag{7}$$

Thus, we will obtain for each set of criteria  $K_E, K_S, K_I$  a continuous set of values  $\{\delta_{Ei}(x); \delta_{Si}(x); \delta_{Ii}(x)\} \in [0; 1]$  on the interval of evaluation points  $x \in [a_0; b_0]$ , according to the evaluated set of coworking spaces,  $i = \overline{1, \bar{n}}$ . For the aggregated evaluation of the expert opinion  $x_k \in [a_0; b_0]$  of the corresponding set of criteria  $k = \{E; S; I\}$ , the membership function  $\theta(\varepsilon_{ki})$  of the maximum value of the weighted sum  $\max_x \delta_{ki}(x) = \varepsilon_{ki}$  is selected. As a result, an aggregated conclusion of the expert's reasoning based on a set of criteria is obtained  $K_E, K_S, K_I$ .

At the third stage, the aggregated conclusions on sets of criteria are normalized according to the following formula:

$$m_k(c_i) = \frac{\varepsilon_{ki} \cdot \theta(\varepsilon_{ki})}{b_0}, k = \{E; S; I\}, i = \overline{1, \bar{n}}. \tag{8}$$

The obtained scores  $m_k(c_i) \in [0; 1]$  characterize the level of quality of coworking, respectively, evaluated according to the sets of criteria  $K_E, K_S, K_I$ . The higher the score, the better the space for work, which provides not only comfortable working conditions but also opportunities for innovative development in a society of like-minded people. Thus, there was a transition from fuzzy linguistic conclusions of the expert to a quantitative assessment. Adequate use of the fuzzy sets increases the degree of validity of future decisions.

Thus, there was a transition from the linguistic fuzzy conclusions of the expert to a quantitative assessment. Adequate use of the apparatus of fuzzy sets increases the degree of validity of future decisions.

During the expert evaluation, the expert formed a set of evaluation criteria and evaluated a set of coworking spaces based on them. Then, at the next – fourth stage, the DM must make a choice, considering its target needs  $G_E, G_S, G_I$ . Such goals are correlated according to the set of evaluation criteria  $K_E, K_S, K_I$  and are proposed by the authors, based on the experience in the subject area.

Since the task of evaluating alternative options of coworking spaces, consisting of three goals, then the vectors  $m_E(C) = \{m_E(c_1), m_E(c_2), \dots, m_E(c_n)\}$ ,  $m_S(C) = \{m_S(c_1), m_S(c_2), \dots, m_S(c_n)\}$  and  $m_I(C) = \{m_I(c_1), m_I(c_2), \dots, m_I(c_n)\}$ , are projected on the three-dimensional coordinate system x, y, z respectively. For each coworking space, the coordinates for the goals  $G_E, G_S, G_I$  are obtained in the form:  $(m_E(c_1), m_S(c_1), m_I(c_1)), (m_E(c_2), m_S(c_2), m_I(c_2)), \dots, (m_E(c_n), m_S(c_n), m_I(c_n))$ .

Next, a three-dimensional vector of DM goals  $T^* = (A_1, A_2, A_3)$ , is considered, which considers his wishes regarding the value of alternative coworking spaces, according to goals  $G_E, G_S, G_I$ . Let's model the vector of DM goals as follows (Kelemen, Gavurova, & Polishchuk, 2022; Polishchuk, 2019).

Let an object with 3 inputs and one output be analyzed:

$$U = (A_1, A_2, A_3). \tag{9}$$

Where  $U$  is the initial evaluation vector  $(u_1, u_2, u_3)$ , and its components can have values from the interval [0; 1], and  $A_1, A_2, A_3$  are input linguistic variables.

Qualitative terms from such term-sets are used to evaluate linguistic variables  $A_1, A_2, A_3$ :

$$A_1 = (a_{11}, a_{12}, \dots, a_{1t_1}), A_2 = (a_{21}, a_{22}, \dots, a_{2t_2}), A_3 = (a_{31}, a_{32}, \dots, a_{3t_3}). \tag{10}$$

Knowledge of the vector of DM goals  $T = (t_1, t_2, t_3)$  is obtained from the fuzzy knowledge base consisting of systems of logical statements - "If - Then, Else", which connect the values of the input variables  $A_1, A_2, A_3$  with one of the possible values  $U$ .

$$\text{If } A_1 = a_{1t_1} \text{ and } A_2 = a_{2t_2} \text{ and } A_3 = a_{3t_3} \text{ Then } U = (u_1, u_2, u_3) \text{ Else ...} \tag{11}$$

Thus, the DM sets the linguistic desire for the vector of goals, which is translated into the vector of the initial quantitative and normalized assessment  $(u_1, u_2, u_3)$ . We denote accordingly  $(u_1, u_2, u_3) = (t_1, t_2, t_3)$ . A fuzzy knowledge base is proposed to evaluate coworking spaces according to the target needs of DM is as follows:

IF we have:

$G_E$  – ecological goal (importance of the object):  $\{a_{11}$  the need for the ratio of price and quality of coworking, then  $u_1 = 0.4$ ;  $a_{12}$  priority need for a good location of the coworking space, then  $u_1 = 0.6$ ;  $a_{13}$  the need for both high-quality office infrastructure and a good location, then  $u_1 = 0.8$ ;  $a_{14}$  significant need for quality office infrastructure, good location and overview of environmental policy, then  $u_1 = 1$ }.

**AND**  $G_S$  – social goal (importance of the subject):  $\{a_{21}$  minimal need for a community of like-minded people, participation in joint projects, moral support, exchange of new ideas and knowledge, then  $u_2 = 0.2$ ;  $a_{22}$  low need for a community of like-minded people, participation in joint projects, moral support, exchange of new ideas and knowledge, then  $u_2 = 0.4$ ;  $a_{23}$  average need for a community of like-minded people, participation in joint projects, moral support, exchange of new ideas and knowledge, then  $u_2 = 0.6$ ;  $a_{24}$  high need for a community of like-minded people, participation in joint projects, moral support, exchange of new ideas and knowledge, then  $u_2 = 0.8$ ;  $a_{25}$  very high need for a community of like-minded people, participation in joint projects, moral support, exchange of new ideas and knowledge, then  $u_2 = 1\}$ .

**AND**  $G_I$  – innovative goal (interaction of subjects and business for the development of innovations):  $\{a_{31}$  is not interested in the innovative component, then  $u_3 = 0.2$ ;  $a_{32}$  may be some innovative possibilities, then  $u_3 = 0.5$ ;  $a_{33}$  are interested in new opportunities for business and financing, then  $u_3 = 0.8$ ;  $a_{34}$  the need for the best opportunities for the development of one's innovative product and its financing, then  $u_3 = 1\}$ ;

**THEN** we can formulate the logical statement as follows  $U = (u_1, u_2, u_3)$ .

The system analyst can change quantitative levels or rules in goals. Therefore, the knowledge base is open, and the number of goals can be changed if necessary.

Next,  $M_A$  is proposed – a model for aggregating the raw data of the fuzzy coworking evaluation model  $M_C$  and goal customer needs.

For this, for all evaluated coworking spaces, there are values  $Z_i = (z_{Ei}, z_{Si}, z_{Ii}), i = \overline{1, n}$ , which characterize the relative estimates of the proximity of the evaluated coworking spaces to the vector of DM goals, for each individual goal  $G_E, G_S, G_I$ , while removing the issue of different evaluation scales (Polishchuk, 2019):

$$z_{Ei} = 1 - \frac{|u_1 - m_E(c_i)|}{\max\{u_1 - \min_i m_E(c_i); \max_i m_E(c_i) - u_1\}}, \tag{12}$$

$$z_{Si} = 1 - \frac{|u_2 - m_S(c_i)|}{\max\{u_2 - \min_i m_S(c_i); \max_i m_S(c_i) - u_2\}}, \tag{13}$$

$$z_{Ii} = 1 - \frac{|u_3 - m_I(c_i)|}{\max\{u_3 - \min_i m_I(c_i); \max_i m_I(c_i) - u_3\}}. \tag{14}$$

The evaluation of coworking spaces according to this approach will have meaning, with two or more alternative options.

Furthermore, for the aggregation of Z values, it is proposed to use the modelling of uncertainties of the "average value" form in a three-dimensional space, using a cone-shaped membership function in the space of estimates  $[0; 1]$ . The value of the center of the base of the cone will be the unit vector  $(x_1^0; x_2^0; x_3^0) = (1; 1; 1)$ , and scaling according to the coordinates of the vector  $Z_i$  was obtained experimentally –  $(3; 3; 3)$ . Then, the three-dimensional conical membership function will be given by the formula (Kelemen, Gavurova, & Polishchuk, 2022):

$$f_i = \begin{cases} 1 - \alpha_i, & \text{if } \alpha_i < 1 \\ 0, & \text{otherwise} \end{cases}, \tag{15}$$

$$\alpha_i = \frac{1}{3} \cdot \sqrt{(z_{Ei} - 1)^2 + (z_{Si} - 1)^2 + (z_{Ii} - 1)^2}, i = \overline{1, n}.$$

Thus, the initial estimates of  $f_i$  from the interval  $[0; 1]$  respectively for n coworking spaces.

Based on the received evaluations, a ranking series of alternative options  $C = \{c_1; c_2; \dots; c_n\}$  is built, and the DM chooses the best co-working according to its own target priorities:

$$C^* = \max_i f_i \quad i = \overline{1, n}. \tag{16}$$

The vector of DM goals ensures the construction of a ranking series of coworking space alternatives  $C = \{c_1; c_2; \dots; c_n\}$ , given by the evaluation vectors, while the safety of choosing alternative options according to the goal needs is increased.

Other important factors in choosing a coworking space can influence the decision-making process of the DM. For example, if an employee performs most of his work remotely, the focus should be on choosing a co-working space that is close to home or in a place that is easy to get to. Another example is if an employee regularly visits his clients, then their location is also important. In this case, from the obtained ranking series, the DM selects  $g$  ( $g < n$ ) coworking spaces. Their DM is evaluated with the help of fuzzy multicriteria models previously developed by the authors (Kelemen, Gavurova, & Polishchuk, 2022; Polishchuk, 2019). Only additional important factors for the client are considered as a criterion set. At the same time, evaluations of alternatives should be measured  $f_i$ .

We present a system of input data for evaluating coworking spaces, which are the basis of the proposed fuzzy models of the researched problem. The criteria for evaluating coworking spaces are presented in the form of a question about substantiating the quality of a coworking space in terms of environmental friendliness, sociality, and innovativeness. Based on information and knowledge about coworking, the expert assigns a score from the interval  $x \in [a_0; b_0]$  for each criterion according to the proposed fuzzy statements  $CL = \{A; B; C; D\}$ . The system of criteria is proposed as follows.

$K_E$  – set of evaluation criteria for the coworking facility itself:

$K_{E1}$  – the general design of the space includes all modern components of a co-working space, such as meeting rooms; halls for events (conference halls); individual boxes; telephone boxes; discussion booths (round tables); game areas; recreational/lounge areas; terraces; cafe/dining room and others.

$K_{E2}$  – workplace quality: furniture made of ecological materials, availability of necessary equipment, availability of stationery, high-speed Internet.

$K_{E3}$  – quality of additional services: room with office equipment, unlimited snacks/drinks or lunches, events, training, workshops, administrative support, virtual office, and technological platforms.

$K_{E4}$  – the location of the co-working space represents a good transport network and infrastructure around the coworking space, such as restaurants, grocery stores.

$K_{E5}$  – availability of support namely: administrative support, mail and package delivery, front desk and office management, event planning, catering and other services along with technical support to facilitate remote conferencing and presentation capabilities.

$K_{E6}$  – ratio of price and quality of coworking space.

$K_{E7}$  – coworking space provides an environmental policy, this is policy aimed at ensuring the effective use and reproduction of natural resources, environmental protection and ensuring the environmental safety of co-working space activities.

$K_S$  – set of evaluation criteria for coworking entities:

$K_{S1}$  – possibility of working in groups, exchange of new contacts.

$K_{S2}$  – the possibility of working on joint or similar projects.

$K_{S3}$  – availability of social contact, moral support, opportunities for communication, friendly atmosphere.

$K_{S4}$  – brainstorming, exchange of new ideas, opportunities, knowledge, advice, and feedback between other customers of the coworking space.

$K_I$  – set of criteria for evaluating innovative potential:

$K_{I1}$  – availability of opportunities to create innovation (art object) in the form of a new product or service.

$K_{I2}$  – availability of opportunities to increase turnover by promoting goods, services, and works of art, through the tools of industry events, social networks, quality marketing, etc.

$K_{I3}$  – the possibilities of various financing tools for an innovative or artistic project, in the form of technical, legal, or economic support from the coworking space.

$K_{I4}$  – availability of new opportunities for business from the coworking space side.

$K_{I5}$  – a coworking space increases the productivity of work on an innovative or artistic project.

The given sets of criteria are open, and the model does not depend on the number of criteria. Experts can always add their metrics when customizing the rating model for different types of coworking spaces (Clifton et al., 2022).

**2. Examples**

The results of the research on the example of evaluating 5 coworking spaces  $C = \{c_1; c_2; \dots; c_5\}$ , the data of which are taken from open sources (Lange, & Bürkner, 2017). The calculation will be carried out based on a technology of evaluation and selection of co-working spaces according to the target needs of customers. For this purpose, an expert evaluation was conducted based on the given systems of criteria  $K_E, K_S, K_I$ . The evaluation was carried out by the authors within the field of innovative business, members of various commissions and competitions for evaluating grants, scientific, technical, and start-up projects. We set our statements on the interval of numbers  $x \in [1; 10]$  using one of the linguistic statements CL. Also, let DM determine the weighting factors for each criterion. Input data and weighting factors are given in the Tab. 1.

Table 1

Input data from the expert assessment of coworking spaces

System criteria	Name	Weight	Type of linguistic statement / estimation limits x				
			$c_1$	$c_2$	$c_3$	$c_4$	$c_5$
$K_E$	$K_{E1}$	10	A / from 7 to 9	C / is not greater than 5	D / is not less than 3	A / from 5 to 7	B / close to 8
	$K_{E2}$	9	C / is not greater than 7	B / close to 9	B / close to 8	A / from 6 to 9	B / close to 8
	$K_{E3}$	7	D / is not less than 5	C / is not greater than 8	A / from 7 to 10	B / close to 9	B / close to 7
	$K_{E4}$	8	B / close to 7	B / close to 6	C / is not greater than 7	D / is not less than 7	D / is not less than 7
	$K_{E5}$	8	A / from 8 to 9	C / is not greater than 5	D / is not less than 5	A / from 8 to 9	A / from 7 to 9
	$K_{E6}$	9	C / is not greater than 6	A / from 7 to 9	C / is not greater than 6	D / is not less than 8	A / from 9 to 10
	$K_{E7}$	10	D / is not less than 6	B / close to 6	B / close to 8	A / from 5 to 8	A / from 6 to 9
$K_S$	$K_{S1}$	7	C / is not greater than 5	B / close to 6	C / is not greater than 8	A / from 5 to 9	B / close to 7
	$K_{S2}$	8	D / is not less than 7	D / is not less than 8	A / from 5 to 6	B / close to 9	C / is not greater than 6
	$K_{S3}$	7	A / from 7 to 9	A / from 6 to 8	C / is not greater than 8	A / from 7 to 9	D / is not less than 8
	$K_{S4}$	8	C / is not greater than 6	C / is not greater than 6	B / close to 5	C / is not greater than 6	A / from 3 to 5
$K_I$	$K_{I1}$	9	C / is not greater than 5	A / from 5 to 6	A / from 7 to 9	D / is not less than 9	C / is not greater than 5
	$K_{I2}$	10	A / from 7 to 9	B / close to 7	B / close to 5	A / from 7 to 9	B / close to 7
	$K_{I3}$	10	D / is not less than 6	C / is not greater than 8	B / close to 6	D / is not less than 8	B / close to 6
	$K_{I4}$	8	A / from 4 to 6	D / is not less than 7	A / from 4 to 6	A / from 6 to 9	D / is not less than 5
	$K_{I5}$	8	B / close to 7	C / is not greater than 7	B / close to 8	B / close to 9	A / from 5 to 7

First, weighting coefficients are normalized within the appropriate set of criteria  $K_E, K_S, K_I$ , according to formula (6). The result will be presented in the form of a vector:  $\alpha_E = (0.16; 0.15; 0.12; 0.13; 0.15; 0.16)$ ,  $\alpha_S = (0.23; 0.27; 0.23; 0.27)$ ,  $\alpha_I = (0.2; 0.22; 0.22; 0.18; 0.18)$ . Next, we will move from the intervals of fuzzy evaluations of coworking spaces according to the criteria to a single point evaluation within the criteria system  $K_E, K_S, K_I$ . To do this, based on the input data, using the membership functions of criteria (2)–(5), we will construct graphs of experts' conclusions. And for data fuzzification, we will find the weighted sum within one set of evaluation criteria  $K_E, K_S, K_I$  according to formula (7). The results of the calculation, separately for the systems of criteria  $K_E, K_S, K_I$ , will be illustrated on the graphs of the functions built with the help of the specially designed software (Kelemen, Gavurova, & Polishchuk, 2022), Fig. 2.

For the aggregated assessment of the expert opinion of the corresponding system of criteria  $k = \{E; S; I\}$ , selected the membership function  $\theta(\varepsilon_k)$  of the maximum value of the weighted sum  $\max_x \delta_k(x) = \varepsilon_k$ . Also, the aggregated conclusions on sets of criteria are normalized according to formula (8), the result will be presented in the form of Tab. 2.

Thus, we moved from the linguistic fuzzy conclusions of the expert to a quantitative assessment. Next, we move to the stage when DM sets its target needs  $G_E, G_S, G_I$ , IF there is a significant need for high-quality office infrastructure, a good location and an overview of environmental policy ( $u_1 = 1$ ) AND a high need for a community of like-minded people, participation in common projects, moral support, exchange of new ideas and knowledge ( $u_2 = 0.8$ ) AND interested in new opportunities for business and financing ( $u_3 = 0.8$ ) THEN  $U = (1; 0.8; 0.8)$ .

Further evaluation takes place according to the model of aggregation of output data  $M_A$ . First, for all evaluated co-working spaces, there are values  $Z_i = (z_{Ei}, z_{Si}, z_{Ii}), i = \overline{1,5}$ , according to formulas (12)–(14). We will present all the calculation results in Tab. 3.

Table 2

**Results of aggregated findings of coworking spaces**

	C <sub>1</sub>			C <sub>2</sub>			C <sub>3</sub>			C <sub>4</sub>			C <sub>5</sub>		
	$\varepsilon_1$	$\mu(\varepsilon_1)$	$m(c_1)$	$\varepsilon_2$	$\mu(\varepsilon_2)$	$m(c_2)$	$\varepsilon_3$	$\mu(\varepsilon_3)$	$m(c_3)$	$\varepsilon_4$	$\mu(\varepsilon_4)$	$m(c_4)$	$\varepsilon_5$	$\mu(\varepsilon_5)$	$m(c_5)$
$K_E$	7	0.94	0.66	6	0.86	0.52	7	0.92	0.64	7	0.93	0.65	8	0.94	0.75
$K_S$	6	0.87	0.52	6	0.92	0.55	5	1	0.5	7	0.87	0.61	6	0.84	0.50
$K_I$	6	0.89	0.53	7	0.95	0.67	6	0.87	0.52	9	1	0.9	6	0.92	0.55

Table 3

Relative estimates of the proximity of the evaluated CS to the vector of DM goals

	C <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>	C <sub>4</sub>	C <sub>5</sub>
Estimate $z_E$ relative to the goal $G_E$	0.29	0	0.26	0.28	0.49
Estimate $z_S$ relative to the goal $G_S$	0.07	0.17	0	0.36	0.01
Estimate $z_I$ relative to the goal $G_I$	0.04	0.51	0	0.64	0.11

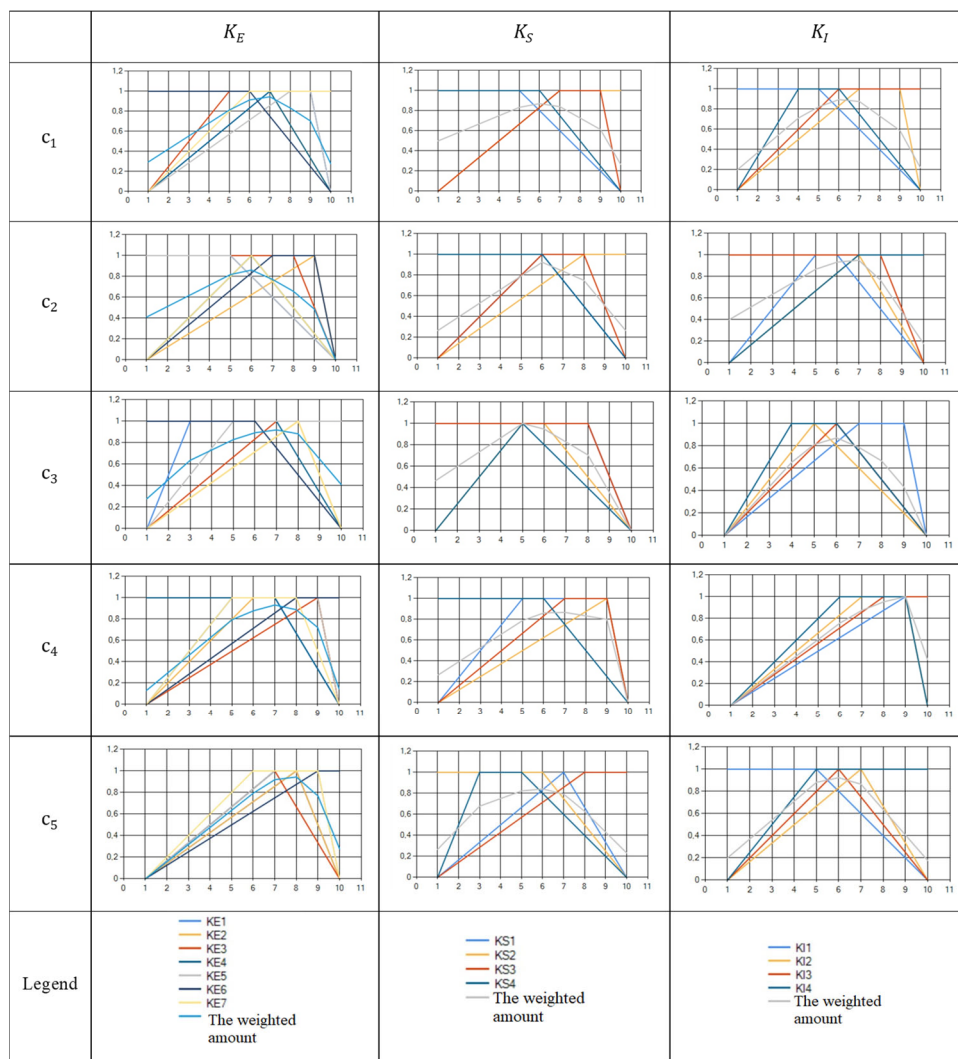


Fig. 2. A fragment of the calculation result

Next, a three-dimensional cone-shaped membership function according to formula (15) is used to aggregate Z values:  $f_1 = 0.49; f_2 = 0.54; f_3 = 0.47; f_4 = 0.66; f_5 = 0.53$ . Based on the received evaluations, a ranking series of coworking spaces is built, and the DM selects the best coworking space, (16):  $(c_4; c_2; c_5; c_1; c_3)$ . The results reveal that the best alternative solution for choosing a CS is  $c_4$ .

**Discussion and conclusions**

The research is based on the apparatus of fuzzy sets, which allows one to increase the degree of validity of decisions. The input data are given in estimation intervals that consider all possible scenarios. An intellectual analysis of knowledge is used to process input information, the subjectivity of experts is revealed, and the final assessment is presented in quantitative

form. The value of the model is that it allows one to obtain a quantitative assessment of CS from input fuzzy expert data, and the assessment procedure for experts is simple and natural. The input data are processed by appropriate fuzzy models, revealing that quality of additional services (workshops, virtual office, and tech platforms) and availability of support (administrative and technical support) are decisive factor in the case facility itself. The results highlight the importance of collaboration on joint projects and the availability of social contact (moral support and a friendly atmosphere) among the needs of users. We identified opportunities to create innovation, and spaces that increase the productivity in project-oriented production are among criteria for innovation potential in CS. At the output of the model, we have an initial quantitative assessment and a series of CS for users to choose from, considering their needs in a systematic manner.

The study presents a technology to evaluate and selecting CS following the target needs of customers to provide some information on the importance and definition of the needs and tensions related to these needs. The model considers the users' goals regarding an environment that increases work productivity, namely: environmental goal (importance of the object), social goal (importance of the subject), and innovation goal (interaction of subjects and business to develop innovation). A developed fuzzy knowledge base for evaluating coworking spaces for targeted DM needs can be easily adapted to various other DM goals, especially with increasing diversity among CS members. The obtained evaluation and the ranking series of alternative options for CS built on their basis reflects on the degree of validity for the decision. Furthermore, the model increases the degree of reasonableness of the choice of CS, and there is an opportunity to involve additional criteria for evaluation and use fuzzy multi-criteria models, revise the goal needs of DM, change the parameters of evaluation models for sustainability of ideas in communities.

A limitation of our study was the use of different types of membership functions for fuzzy CL statements and the aggregation of Z values. As is known, the choice of the type of membership functions and the use of different types of convolutions can lead to ambiguity in the results, but this does not affect the content of the evaluation, since the system's analyst can always adjust the levels of decision-making. Another limitation is related to the geographical context in which this study was conducted. Although the research was conducted on the territory of three countries: Ukraine, the Czech Republic, and Poland, it is also important to reproduce it in other countries. This allows us to compare the results, verify and unify the developed model.

The rationality of the obtained initial estimate  $f$  for building a ranking series of CS proves the advantages of the developed model. The reliability of the obtained results is confirmed by the results of research and is ensured by the justified use of the apparatus of fuzzy sets, intellectual analysis of knowledge and system approach towards creative communities. Thus, the hypothesis of this study was proved.

The main goal of the conducted research is to develop a technology decision support of evaluation and selection of coworking spaces according to the goal needs of customers. The technology is aimed at supporting the decision-making processes of users in CS regarding the evaluation and selection of them for the workplace, according to their own goal needs, impartial evaluation of coworking spaces, and increases the safety of their choice. At the same time, the following results were obtained:

- for the first time, a system of criteria for evaluating coworking spaces, a total of 16, was developed to justify their quality in terms of environmental friendliness, sociality, and innovativeness. The set of criteria is open, and the model does not depend on their number. Experts can always add their metrics when customizing the rating model for different types of coworking spaces;

- for the first time, a fuzzy model of evaluation and selection of coworking spaces was developed following the goal needs of customers. The model is based on the opinions of experts, in a certain interval of values of the quality of coworking according to certain indicators. At the output of the model, we receive an aggregated assessment based on an expert assessment of the infrastructure of the coworking facility, environmental policy, social atmosphere and knowledge exchange of coworking subjects, innovative potential, and also takes into account the goals of employees regarding their needs in the workspace in terms of environmental friendliness, sociality, and innovativeness. The fuzzy model consists of two sub-models: fuzzy evaluation of coworking according to the proposed set of criteria and data aggregation using goal customer needs;

- the research results were tested on the example of the evaluation of five coworking spaces, the real data of which were taken from open sources. At the same time, the adequacy of the fuzzy model, its sub-models, and system of criteria developed in the work was experimentally confirmed.

The obtained results demonstrate applied value and prove the scientific hypothesis of this study. The technology was presented to provide insight into decision making for entrepreneurial sustainability in CS by emphasizing the coworking facility, community, and the innovative potential.

Further research of the problem can be seen in the implementation of additional evaluation criteria, on their basis the development of a fuzzy multi-criteria model, and the adjustment of the system of criteria for clearly defined types of co-working spaces. The next stage, based on fuzzy models, will be the construction of software in the form of a web platform, which will contain an innovative tool for choosing the best CS, considering the goals and wishes of customers. Together, the developed fuzzy models, criteria information systems, and software support will constitute an innovative information technology for the evaluation and selection of co-working spaces, which will support the concepts of the European Green Deal and Industry 5.0.

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## ТЕХНОЛОГІЯ ОЦІНЮВАННЯ ТА ВИБОРУ КОВОРКІНГ-ПРОСТОРІВ ВІДПОВІДНО ДО ЦІЛЬОВИХ ПОТРЕБ КЛІЄНТІВ

Основною метою пропонованого дослідження є розроблення технології оцінювання та вибору коворкінгів відповідно до цільових потреб клієнтів. Для цього були розроблені: нечітка модель оцінювання коворкінгу, модель агрегування вихідних даних нечіткої моделі для оцінювання коворкінгу та цільових потреб клієнтів, представлено валідацію дослідження на основі п'яти коворкінгів. Дослідження базується на апараті нечітких множин, що дає змогу підвищити рівень обґрунтованості рішень. Вхідні дані надано в інтервалах оцінювання, що враховують усі можливі сценарії. Для оброблення вхідної інформації використано інтелектуальний аналіз знань. У процесі роботи виявлено суб'єктивізм експертів, підсумкову оцінку виставлено в кількісному вигляді. Цінність моделі полягає в тому, що вона дає змогу отримати кількісну оцінку коворкінгів із вхідних нечітких експертних даних, а процедура оцінювання для експертів є простою та природною. Модель урахує цілі користувачів щодо середовища, яке підвищує продуктивність праці, а саме: екологічні, соціальні й інноваційні цілі. На виході моделі ми маємо початкову кількісну оцінку та рейтинговий ряд коворкінгів. Проведені дослідження сприяють розвитку коворкінгів, підвищенню їхньої ефективності та відповідності потребам ринку. Це також корисно для фрилансерів, команд стартапів і малого бізнесу, які отримують інструмент для вибору простору, що відповідає їхнім потребам з позиції розташування, бюджету й умов.

**Ключові слова:** багатокритеріальна оцінка альтернатив, нечіткі множини, нечітка логіка, коворкінг, експертна оцінка, особа, що ухвалює рішення.

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