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Research paper

Assessment of the technical condition of heritage buildings with the use of fuzzy logic

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Abstract: Construction objects must be protected not only at the stage of their construction, but also during exploitation. Particular attention should be paid to objects included in the list of monuments. The Act on the Protection of Monuments and the Guardianship of Monuments states that any building that is important for history and science can become a heritage building and should therefore be preserved. The aim of this article was to improve the method of visual assessment of the technical condition of heritage buildings with the use of fuzzy logic. The improved method is to facilitate the comparison of assessments of the technical condition of a building performed at intervals specified in the regulations, often by different people. The research was conducted on the basis of technical expertise prepared for five examined buildings that were tenement houses entered in the register of monuments. The use of the visual method provides for the assessment of individual elements of the object by an expert and a verbal description of the elements using a five-point scale. A significant limitation of this method is uncertainty associated with the exact ranges of the acceptable values, as these ranges are subjective and depend on the opinion of an evaluator. The impact of this limitation can be reduced by applying fuzzy logic. In the fuzzy logic model, as input variables the following were applied; assessments of the technical condition of individual elements of the object (underground structure, load-bearing walls, ceilings, roof, other elements) and an integral indicator of the technical condition of the entire historic object, calculated as the output value.

Keywords: historic buildings, fuzzy logic, visual method, technical condition assessment

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1. Introduction

In order to support decision-making on facility management, it is advisable to diagnose and forecast its technical condition, which is characterized by the values of a set of controlled parameters. The better the diagnostics is carried out, that is the more precisely the technical condition of the facility is determined, the sooner actions can be taken to eliminate the failure.

There are legal acts in Polish law that refer to historic buildings. The monument according to the act of 23 July 2003 on the protection and care of monuments [1] means real estate or movable property, their parts or units, being the work of man or related to his activity and being a testimony to a bygone era or events whose preservation is in the social interest due to their historical, artistic or scientific value. Monuments are undoubtedly the national heritage, however, in order to retain their functional and aesthetic values, they must be subject to periodic inspections and renovation in accordance with Art. 62 of the Construction Law [2]. Regular inspections, and thus possible repairs based on expert opinions on their technical condition, enable to eliminate expensive repairs of heritage buildings, which, if not performed on time, may endanger the lives and property of the residents [3]. In heritage tenement buildings, structural elements are more exposed to destructive factors than in modern buildings, due to the type of raw materials used to produce building components and the technology of works. Therefore, it is of great importance to correctly determine the technical condition of the described objects.

The technical condition of an object can be assessed based on the value of the set of controlled parameters of its functioning, which is formed by the matrix A, whose elements a_{ij} are the result of i – this observation with j – this parameter; $i = 1, \ldots, l$, $j = 1, \ldots, p$ (l – number of observations, p – number of diagnostic parameters of the object). In addition, there is an unknown relationship between the diagnostic parameters of an object and its states.

2. Literature review

Other scholars have also looked for ways to solve the difficult problem of the technical valuation of historic buildings. For example, Jaskowska-Lemańska, Wałach and Sagan, based on a comprehensive diagnostic study, have developed a flow chart that illustrates the procedures for assessing the technical condition of historical buildings and helps in determining damage [4]. Ilter and Ergen have explored the prospects for using BIM (Building Information Modeling) in the renovation and maintenance phases of buildings, and are introducing roadmaps to overcome the identified challenges [5]. The following study was devoted to the implementation of the HBIM (Historic Building Information Modeling) approach for the reconstruction and preservation of historic buildings. The authors proposed to use the method of sharing and reusing information obtained as a result of archival analysis, damage survey and diagnostic investigation [6].

A numerical parameter describing the technical condition of a building, or its components is the degree of wear expressed as a percentage. Among methods that determine the degree of wear, time and visual methods are most often distinguished [7–10]. Calculations of the technical condition using the time method can be performed with the use of selected formulas depending on the general condition of a building [11–13]. This method assumes the same linear or non-linear wear of a building or building components. The time-based method is not precise as it only takes into account: building age – t, and building durability – T. Determining the "t" parameter may be problematic due to the construction of buildings in stages, which may be performed even over the period of several years. The durability of a building, on the other hand, is determined according to the tables available in the literature. The most popular formulas used in the temporal method are Ross formula, Ross–Unger formula, and Ross–Eytelwein formula.

On the other hand, visual methods are applied to determine the wear of building components by means of observations during on-site inspections and to determine the degree of wear through expertise. According to the above-mentioned method, the percentage of wear of each element is first determined based on the adopted criterion of assessment and subjective assessment of a person who determines the wear of the object and classifies the technical condition on the basis of the relationship between the technical condition of the object and the degree of its technical wear.

Neither temporal method nor the visual one, give precise results. The literature there are also other methods for determining the degree of technical wear of a building based on modeling with the use of artificial intelligence. Such a description of a building with the use of artificial neural networks, was presented among others by Bucoń and Sobotka [14]. Methods using the artificial neural network are extremely time-consuming and require large amount of data. The authors of this study decided to take the challenge of proposing an easier method than the ones based on the neural network, but more precise than the temporal or visual methods for determining the technical condition of an object. A method that will allow, in subsequent years of the facility's operation, to easily compare the degrees of wear of a given facility, eliminating errors resulting from the researcher's assessment.

Based on the publicly available documentation for construction works that, according to the Construction Law, are necessary to be performed on each object at the time intervals specified in the regulations, that is periodic inspections of objects in which the visual method is used to assess the technical condition, it was decided to improve the visual method by applying fuzzy logic. A significant limitation of the visual method mentioned above is the uncertainty related to the exact ranges of the acceptable values, since these ranges are subjective and depend on the opinion of a specific person. The impact of this limitation can be reduced by applying fuzzy logic.

Rules of fuzzy logic enable to model a system in the absence of traditional methods and are based on precise mathematical calculations. At the same time, fuzzy logic methods do not replace traditional methods, but rather complement them.

One of the first publications available in the literature on the theory of fuzzy sets is the work of Lotfi Zadeh, published in 1965 [15]. The concept of a fuzzy set gave rise to a new impetus in mathematical and applied research, which quickly proposed fuzzy generalizations of all major formal logical concepts. Behind the introduction and development of fuzzy logic was reasoning that real decisions are based on subjective perceptions and not on objective facts. Fuzzy logic is a way to formalize people's ability to integrate uncertainty with logical reasoning, allowing them to make decisions effectively in a complex world.

Some studies in which fuzzy logic was used to solve various research problems are described below. Due to the fact that the planning and implementation of construction projects takes place under conditions of uncertainty, N. Ibadov and J. Kulejewski in 2019 proposed to create an alternative model with a fuzzy decision node based on classic network models [16]. This approach allows for the modeling of alternative activities. The proposed alternative network model with a fuzzy decision node allows for a comprehensive analysis with the possibility of easily taking into account and modeling the uncertainty of the input data.

In 2018 E. Plebankiewicz and D. Wieczorek presented works whose main purpose was to verify the correct operation of the fuzzy risk assessment module in life cycle of buildings [17]. The authors examined the module's sensitivity to a possible change in parameters, which, as a result of modification, may affect the final result of the calculations. Based on the research results, they recommended the most appropriate sets of parameters that may affect the final result of the calculations. In the article from 2016, by E. Plebankiewicz, K. Zimorek and D. Wieczorek present an approach to assessing the technical condition of a building throughout its life cycle in terms of sustainable development [18]. The paper describes the main tools, assessment methods and cost analysis methods throughout the life cycle of a building, such as life cycle assessment, life cycle management, life cycle cost and social life cycle assessment. The model is based on the fuzzy set theory, which allows to include the risk related to sustainable development, investment management and social costs in the calculations. The costs incurred in the subsequent stages of a building life cycle are separately analyzed and modeled using the membership function.

Another example of the application of fuzzy logic was given by J Konior who defined the aim of the study as an analysis of symptoms of a decrease in efficiency of the tested elements, that is the identification of the mechanism of defect formation [19]. The scope of work required the creation of an original qualitative model of point defects and its conversion into a quantitative one. This enabled the analysis of cause-and-effect phenomena "defect – technical wear" related to the most essential elements of residential buildings. The research procedure was conducted in accordance with the fuzzy set theory, which made it possible to describe the qualitative model of point defects and transform it into a quantitative model.

V. Lequesteboumes Borges, V. Michele Tereza, M. Carvalho in their paper, compiled a list of main risks associated with the implementation of BIM in Brazilian public institutions [20]. The risk was defined in accordance with two aspects: probability of occurrence and impact. These data were transferred to the inference system based on fuzzy rules. In this way, through fuzzy logic, a list of the main threats related to the BIM implementation was generated.

Another example of the use of fuzzy logic is a presentation of a new approach to maintaining systems operating in conditions of significant uncertainty, based on the implementation of the error tolerance concept [21]. The authors introduced Maintenance Support Potentials (MSP) as a measure of the organization's ability to maintain support. Moreover, based on the SME definition, they developed a fuzzy method of assessing the potential level of maintenance support. The proposed approach considers two main parameters of SMEs – the potential level of readiness and the importance of the process.

Faqih and Zayed [22] in 2021 noticed that the existing models for assessing the technical condition of facilities are subjective, time-consuming and tedious. They proposed a model that considers the physical condition of the building and environmental conditions. This model employs the principles of fuzzy logic, favourably influencing the obtained results, eliminating the human factor, however it only pertains to concrete objects.

Kartavykh et al. [23] in 2020 also noticed the problem of subjective expert judgment when assessing the technical condition of facilities. Their model with the application of fuzzy logic, which they proposed, is applicable at the level of research used to assess building objects. Since the process of conducting research is accompanied by various types of uncertainties, and the final conclusions of experts are often based on heuristics, the authors recommend the application of the principle of fuzzy inference adaptation.

In 2016–2018, Trechnuk et al. [24] conducted a series of studies on solving issues related to modelling and development of intelligent systems for assessing the technical condition of building structures. The intelligent system for assessing technical condition was created on the basis of the fuzzy knowledge base and the modification of the Takagi-Sugeno-Kang fuzzy network. The authors conclude that the use of a fuzzy network when solving the tasks of assessing the technical condition of a structure extends the possibilities of intelligent systems, reduces the risk of making wrong decisions by increasing the reliability and speed of modelling.

The above-mentioned examples of the use of extensive mathematical models, including fuzzy logic, which have already been used by scientists to solve various problems in the construction industry, motivated the authors to improve the method of visual assessment of the technical condition of heritage buildings using fuzzy logic. The study was conducted based on technical expertise prepared for five examined buildings that are heritage tenement buildings. The use of the visual method provides for the assessment of individual elements of the object by an expert and a verbal description of the elements using a five-point scale. A considerable limitation of this method is uncertainty related to the exact ranges of acceptable values, as these ranges are subjective and depend on the opinion of a specific person. The impact of this limitation can be reduced by applying fuzzy logic. In the fuzzy logic model, the following input variables were applied; assessments of the technical condition of individual elements of an object (underground structure, load-bearing walls, ceilings, roof, other elements) and an integral indicator of the technical condition of the entire heritage building, calculated as the output value.

3. Methodology

The research was conducted using a modified visual method. The visual method should be performed by a person with appropriate expertise and based on a thorough analysis of each damaged element. In the first place this method determines the percentage of wear of each element based on the evaluation criterion (Table 1) and the subjective opinion

Table 1. Classification of the technical condition of an element/building [28]

<table>
<tr><th>Classification of the technical condition of an element / building</th><th>Percentage of element wear [%]</th><th>Element assessment criterion</th></tr>
<tr><td>1</td><td>2</td><td>3</td></tr>
<tr><td>Very good</td><td>0–15</td><td>The element is well kept, maintained, shows no wear and damage. The features and properties of the built-in materials meet the standard requirements</td></tr>
<tr><td>Satisfactory</td><td>16–30</td><td>The building element is properly maintained. Current renovation consisting in minor repairs, additions, maintenance, and impregnation is advisable</td></tr>
<tr><td rowspan="2">Average</td><td>31–50</td><td rowspan="2">There are slight damages and gaps in the building elements which do not endanger public safety. Partial overhaul is advisable</td></tr>
<tr><td>(31 – 40)</td></tr>
<tr><td rowspan="2">Bad</td><td>51–70</td><td rowspan="2">The elements have significant damages, losses and the properties of the built-in materials are of a reduced class. Comprehensive overhaul or replacement required</td></tr>
<tr><td>41 –70</td></tr>
</table>

of an expert and classifies the technical condition. There is the following relationship (formula (3.1)) between the technical condition of the object and the degree of technical wear of the object.

$$S_t = 100 - S_z \quad [\%] \tag{3.1}$$

where: S_t – technical condition of the facility, S_z – degree of technical wear of the object.

The technical condition of the facility is defined in words for the element and the entire building as "very good", "satisfactory", "average" and "bad". The degree of wear of the building's components can be determined using the formula (3.2).

$$S_z = \sum_{i=1}^{n} \frac{u_i \cdot S_{\text{zei}}}{100} \quad [\%] \tag{3.2}$$

where: u_i – the percentage share of the replacement cost of a given element in the structure of the facility replacement cost, acting as a weight, S_{zei} – degree of wear of a given element defined as a percentage, n – number of assessed elements in the facility.

The general technical condition of an object is determined by the total percentage of the wear of elements in the building. This is an accurate method as building components deteriorate at different times [25–27].

A fuzzy system is a computing environment based on the concepts of fuzzy set theory and fuzzy inference. Generally, it provides non-linear transformation of some input fields into output fields. The main advantage of fuzzy inference is that the inference rules can be defined in a precise and consistent manner, while the uncertainty resulting from the input information is solved by defining one or more fuzzy sets for each input.

The basic structure of a fuzzy system consists of three conceptual components [29]:
– a set of inference rules, called the rule base,
– vocabulary that defines fuzzy sets used for modeling dictates in predecessors and inferring rules,
– an inference mechanism that carries out the inference procedure according to the rules and provides input information to produce a reasonable result.

To diagnose the functioning of a technical object, it is proposed to use the Mamdani fuzzy control model, whose creation includes the stages described below [30, 31] (Figure 1).

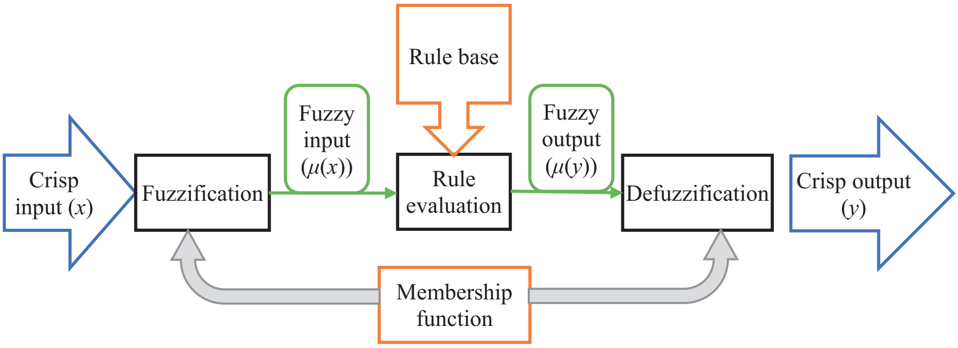

Fig. 1. The structure of the fuzzy logic system

At the stage "Fuzzification", crisp input variables are transformed into fuzzy ones. The purpose of this stage is to establish a correspondence between the numerical value of an input variable (x) and the value of the membership function of fuzzy sets $\mu(x)$. There are different types of membership functions: triangular, trapezoidal, Gaussian, bell-shaped. The type of the membership function is determined by the properties of the modeling object. In this case, expert estimates are linear and can be described by a triangular membership function. Triangular fuzzy numbers are often used to reduce the amount of calculations, obtain average values, and also because they are intuitively easy to make estimates [32]. The peculiarity of triangular fuzzy numbers is that they are determined by three values: the minimum possible value (a), the most expected value (b), and the maximum possible value (c).

In this study, a triangular membership function was used, which can be expressed as [33]:

$$\mu(x) = \begin{cases} 0, & x \le a \quad \text{or} \quad x \ge c \\ \dfrac{x-a}{b-a}, & a \le x \le b \\ \dfrac{c-x}{c-b}, & b \le x \le c \end{cases} \tag{3.3}$$

The next stage, "Rule evaluation" determines the value of the output variable in the form of a fuzzy set ($\mu(y)$) based on the rule base, which is a set of expert linguistic rules of the "If–Then" type. The last stage, "Defuzzification" transforms the fuzzy set into a crisp value of the output variable (y).

The complexity of the diagnostic system is that a large number of rules must be applied. Thus, to assess the technical condition of a building object using 18 parameters, each of which can take one of five values, the full rule base will be 5^{18}. With numerous state parameters, it is advisable to use hierarchically linked knowledge bases, in which the initial variable of one knowledge base is the input for the knowledge base of the highest level of the hierarchy.

Using this approach allows you to reduce the size of the main knowledge base by dividing it into several subordinate databases. In this case, the quality and accuracy of the assessment will not suffer, since each of the elements of the object is involved in the assessment.

In view of the above, it was proposed to first assess the technical condition of the grouped elements of the object (underground structure, load-bearing walls, ceilings, roof and other elements). The grouping was carried out on the basis of the division of the construction object into the main structural elements. After receiving an assessment of each of the grouped elements of the object ($y_1 \dots y_5$), an assessment of the technical condition of the entire object was carried out by calculating the integral indicator (z).

Figure 2 shows a scheme for assessing the technical condition of a historic object using fuzzy logic, where:

$x_{1.1} \dots x_{1.4}$ – these are the elements of group y_1 (underground structure),

$x_{2.1} \dots x_{2.4}$ – these are the elements of group y_2 (load-bearing walls),

$x_{3.1} \dots x_{3.3}$ – these are the elements of group y_3 (ceilings),

$x_{4.1} \dots x_{4.3}$ – these are the elements of group y_4 (roof),

$x_{5.1} \dots x_{5.4}$ – these are the elements that make up the group y_5 (other elements),

$y_1 \dots y_5$ – these are groups of elements that make up the object z (the whole historic object).

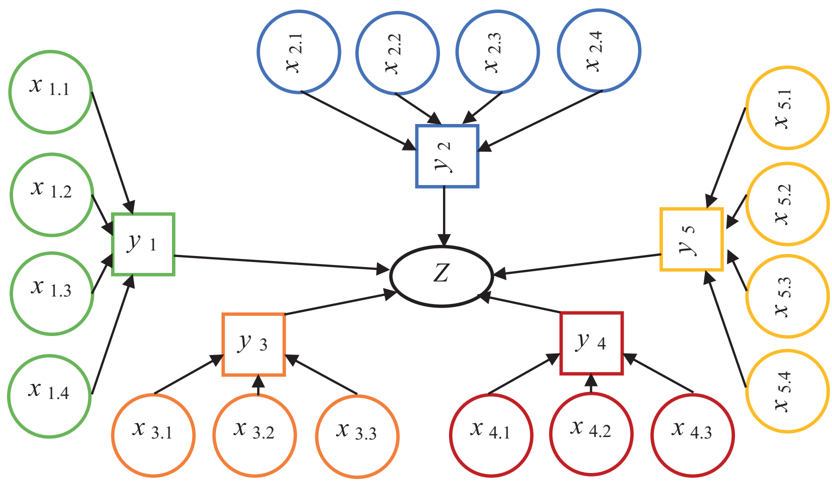

Fig. 2. Scheme for assessing the technical condition of a building object using fuzzy logic

4. Results

The research was carried out on five objects. Each of the examined buildings is a historic tenement house and is located in Warsaw. They were built in 1908, 1910, 1934, 1911 respectively. Each building has one underground storey, 4 buildings have five storeys, and one has four storeys above ground. The usable area of the facilities ranges from 1,300 m^2 to 7,850 m^2.

Table 2 presents the assessment of the technical condition of the elements of five tested buildings. Eighteen individual elements of a building facility were combined into five groups (underground structure, load-bearing walls, ceilings, roof and other elements), technical condition of each element was assessed on a scale [1, 5], where: "very bad" – 1, "bad" – 2, "satisfactory" – 3, "good" – 4, "very good" – 5. In column 6, Table 2, the final technical condition is defined for each group, resulting from the verbal description. In the last column of Table 2, indicators of the technical condition of individual elements of the building structure were calculated using fuzzy logic tools.

Table 2. Assessment of the technical condition of the elements of five examined heritage buildings on a scale from 1 to 5

Object No. / Object element	Continuous footing	Foundation wall	Lintels	Basement floor	Underground construction – verbal description	Underground construction – fuzzy logic*
(1)	(2)	(3)	(4)	(5)	(6)	(7)
I	2	3	3	3	3	2.90
II	2	3	1	1	2	2.13
III	2	3	3	2	2	2.50
IV	3	3	3	3	3	3.04
V	2	3	1	1	2	2.13
Object No. / Object element	Load-bearing walls	Plinth	Lintel	Balconies	Load-bearing walls – verbal description	Load-bearing walls – fuzzy logic
I	2	3	4	3	3	3.00
II	3	3	3	2	3	2.90
III	3	3	3	2	2	2.90
IV	2	3	4	2	3	2.50
V	2	3	2	2	2	2.50

Continued on next page

Table 2 – *Continued from previous page*

Object No. / Object element		Ceiling above the basement	Ceilings of the above-ground storeys (steel-ceramic ceiling)	Ceilings of the above-ground storeys (wooden beam ceiling)	Ceilings – verbal description	Ceilings – fuzzy logic
I		2	3	3	3	2.5
II		2	2	2	2	1.67
III		3	3	2	3	2.5
IV		3	3	2	3	2.5
V		2	2	2	2	1.67
Object No. / Object element		Roof truss	Roofing	Chimneys	Roof – verbal description	Roof – fuzzy logic
I		3	3	4	3	3.04
II		1	3	2	2	2.5
III		3	2	2	2	2.5
IV		1	3	2	2	2.5
V		1	3	2	2	2.5
Object No. / Object element	Stairs	Electrical installation	Sewerage installation	Lightning protection	Other elements – verbal description	Other elements – fuzzy logic
I	3	3	3	2	3	2.9
II	2	2	1	2	2	1.25
III	2	2	2	2	2	1.96
IV	2	2	2	3	2	2.5
V	2	2	2	2	2	1.96

*For easy comparison, the 7-th column of Table 2 showed indicators of the technical condition of individual elements of the building structure were calculated using methodology described in Section 2.

Based on the values of the indicators in Table 2 (column 6), the final indicators of the technical condition of the entire facility were determined using the visual method. The indicators are summarized in Table 3.

Table 3. Final assessment of technical condition of heritage buildings using the visual method

Object No. / Group of object elements	Underground construction	Load-bearing walls	Ceilings	Roof	Other elements	Technical condition of the entire facility
(1)	(2)	(3)	(4)	(5)	(6)	(7)
I	3	3	3	3	3	3
II	2	3	2	2	2	2
III	2	2	3	2	2	2
IV	3	3	3	2	2	2
V	2	2	2	2	2	2

The next stage of research involved creation and application of six fuzzy logic models. Three models had 4 input variables, two models had 3 input variables (which results from the evaluation of the number of items for a given group). The sixth final model had 5 input variables. This model shows the technical condition of the entire facility using fuzzy logic.

Let us give an example of using the model to assess technical condition of one of the elements of a building, namely the underground structure. Figure 3 shows a diagram of the use of a fuzzy inference system to determine the technical condition of an underground structure.

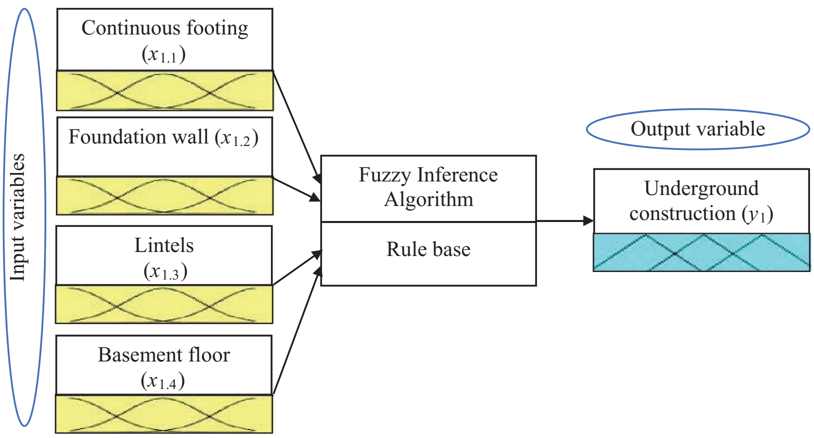

Fig. 3. A schematic example of the use of a fuzzy inference system

Input variables were the values of the technical condition of four elements of the underground structure, namely; foundation strip ($x_{1.1}$), foundation wall ($x_{1.2}$), lintels ($x_{1.3}$), basement ceiling ($x_{1.4}$). The output variable is the technical condition of the underground structure (y_1).

The fuzzy logic system was developed and tested using the Fuzzy Logic Toolbox Matlab R2015b software. A triangular membership function was used to blur the input variables (Figure 4). Each of the variables was described by five sets and falls within the corresponding range: "very bad" – [–1.25, 0, 1.25], "bad" – [0, 1.25, 2.5], "satisfactory" – [1.25, 2.5, 3.75], "good" – [2.5, 3.75, 5], "very good" – [3.75, 5, 6.25].

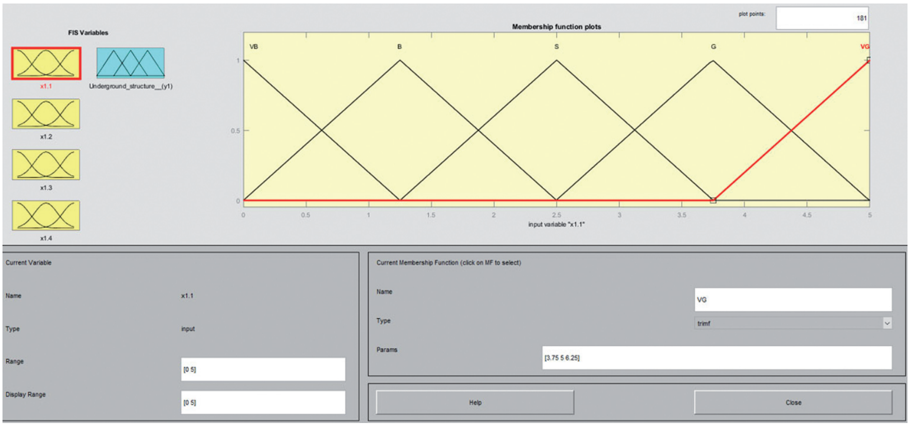

Fig. 4. An example of a triangular membership function

The center of gravity defuzzification method was used to calculate the initial value, in which the initial value is determined based on the center of gravity of the initial fuzzy set.

The inference system checks the values of each linguistic variable using fuzzy logic rules and transforms the input set into an output linguistic variable.

The next step in fuzzy inference is to aggregate the output based on the generated rules. Many rules are simultaneously processed with their further aggregation into a final decision with a fuzzy conclusion. The set of rules in this case included 72 rules (Figure 5).

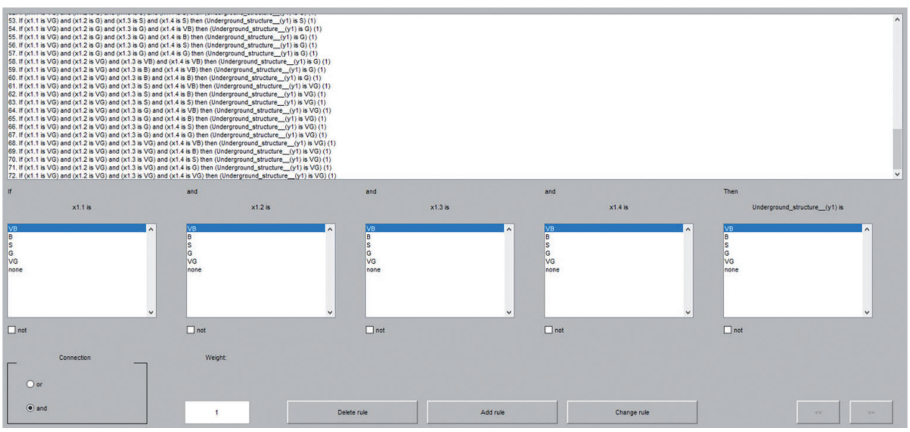

Fig. 5. Fuzzy rules

An example of the rules that were used in this study is presented in Table 4. Hence, if the values of the input indicators are "very good", "satisfactory", "bad", "very bad", the output value is "bad".

Table 4. Examples of rules used in the study

$x_{1.1}$	$x_{1.2}$	$x_{1.3}$	$x_{1.4}$	y_1
very good	very good	good	good	very good
very good	good	good	very bad	good
very good	satisfactory	satisfactory	bad	satisfactory
very good	satisfactory	bad	bad	bad
good	satisfactory	very bad	very bad	very bad

The linguistic output variable y_1 can take one of five values and falls within the appropriate range: "very bad" – [–1.25, 0, 1.25], "bad" – [0, 1.25, 2.5], "satisfactory" – [1.25, 2.5, 3.75], "good" – [2.5, 3.75, 5], "very good" – [3.75, 5, 6.25] (Figure 6).

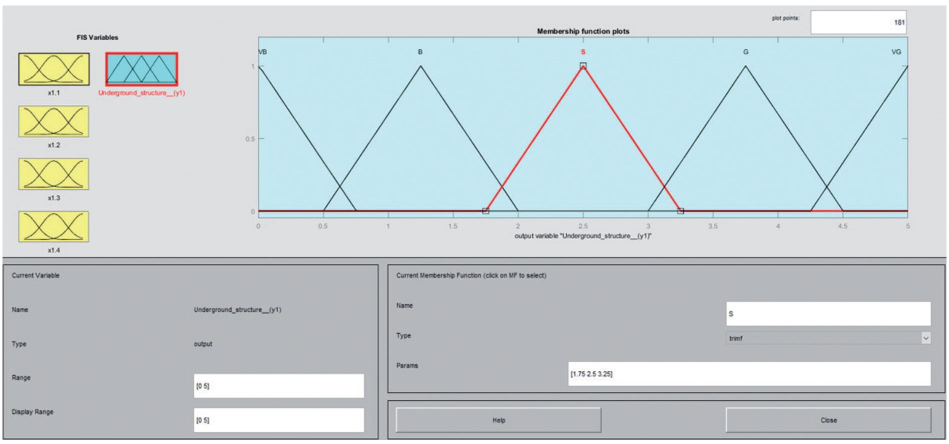

Fig. 6. Sets of the output value of a linguistic variable

The last step is defuzzification, where the output fuzzy linguistic variables are converted to exact numbers. Figure 7 shows an example of the defuzzification stage. For instance, for input fields ($x_{1.1}$, $x_{1.2}$, $x_{1.3}$, $x_{1.4}$), whose numeric values are (2, 3, 1, 1) respectively, the value of the output variable y_1 is 2.13.

Similar models and processes were implemented to determine the value of the output variable for the remaining groups y_2 (bearing walls), y_3 (ceilings), y_4 (roof), y_5 (other elements).

The final fuzzy logic model consists of five input variables ($y_1 \ldots y_5$), 125 rules and one output variable z(technical condition of the entire object).

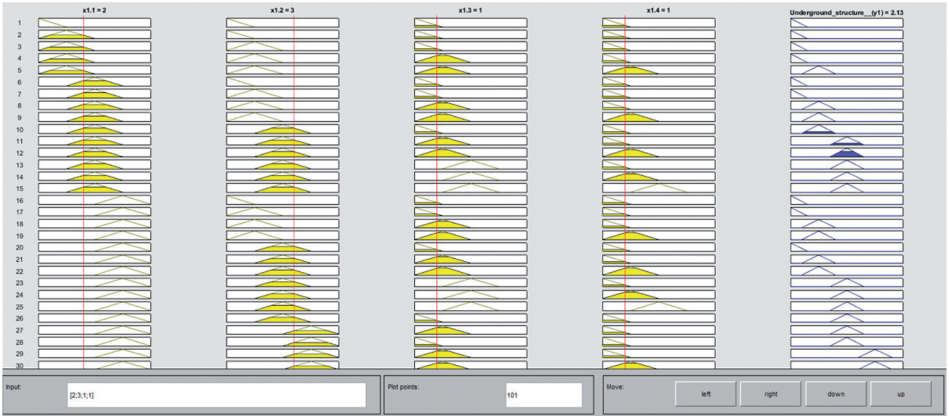

Fig. 7. An example of defuzzification

Table 5 presents the final assessment of the technical condition of historic buildings, calculated using fuzzy logic.

Table 5. Final assessment of the technical condition of heritage buildings

Building no./group of object elements	Underground construction (y_1)	Bearing walls (y_2)	Ceilings (y_3)	Roof (y_4)	Other elements (y_5)	Technical condition of the entire object (z)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
I	2.90	3.00	2.5	3.04	2.9	2.5
II	2.13	2.90	1.67	2.5	1.25	1.78
III	2.50	2.90	2.5	2.5	1.96	2.11
IV	3.04	2.50	2.5	2.5	2.5	2.22
V	2.13	2.50	1.67	2.5	1.96	1.84

For example, for input variables (y_1, y_2, y_3, y_4, y_5) whose numeric values are (2.9, 3, 2.5, 3.04, 2.9) respectively, the value of the output variable z is 2.5. The value of the output variable characterizes the final technical condition of the assessed building.

5. Discussion and conclusions

The fuzzy logic method was applied in previous scientific research on the assessment of technical condition of buildings. It concerned several types of buildings, but the authors did not find a study on the use of the above-mentioned method on heritage buildings. The literature cited below shows that it is beneficial to use fuzzy logic when assessing the technical condition of objects. The application of the fuzzy logic method allows to eliminate the subjectivity of the methods applied so far. Visual assessments of the technical condition of a building are commonly used in practice as a method of assessing the condition of a building. The results of such an evaluation are qualitative and, unfortunately, subjective ones.

With the above in mind, the authors set themselves the goal of the study to develop a quantitative framework for the assessment of the technical condition of heritage buildings, which may minimize subjectivity. However, it should be noted that the proposed method can be applied to various types of buildings. We dealt with heritage buildings because their valuation is more complicated and there are many more factors involved.

Fuzzy logic theory is used to quantify the state while minimizing subjectivity as it deals with imprecise, vague, and ambiguous judgments about belonging relations.

The studies conducted by the authors show that the results obtained with the use of the visual method (Table 3) and the tests obtained with the use of fuzzy logic (Table 5) differ slightly at first sight. For example, for facility no. I according to the visual method, the technical condition of the object is assessed as 3, and according to the fuzzy logic method, it takes the value of 2.5. In the visual method, it was assumed informally that the measure of the technical condition of an object is an integer. In the fuzzy logic method, it is usually a fractional number. Due to this fact, the visual assessment of the technical condition gives less accurate results and can distort reality. For example, two elements scores of 2.50 and 3.0 would be rounded to 3.0, but the real difference between those scores is 20%. Minimizing the researcher's subjective assessment factor and assigning a specific parameter value to a set selected by the program according to predefined rules gives a result that is closer to the actual value.

Due to the above, comparing the current scientific studies with the method proposed by the authors, it can be concluded that the use of fuzzy logic allows to successfully solve problems that arise in subjective assessment of elements of building objects and entire objects. Therefore, the proposed method can be applied in assessing the technical condition of historic buildings. The proposed, improved method makes it easier to compare the assessments of technical condition of a building performed at intervals specified in the Construction Law. The method proposed by the authors reduces subjective influence of an expert on the assessment of the technical condition of objects, which is particularly important when the assessments are made in subsequent years by various entities, and thus by other people. This method allows for a reliable comparison of the condition of objects at intervals, e.g., every 5 years, therefore it is recommended to use fuzzy logic to assess the technical condition of historic buildings. The method of descriptive assessment of the technical condition of a building seems to be imprecise and therefore a quantitative method is recommended since it describes the technical condition of a building in more detail by using fractional numbers.

The direction of future research may be the use of different weights for the elements of the FL model, the use of different trapezoidal, Gaussian, bell-shaped membership functions. In addition, an increase in the number of technical state assessments using the proposed method will allow creating a knowledge base and, in the future, using neural network tools to predict the state of heritage buildings.

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Ocena stanu technicznego obiektów zabytkowych z wykorzystaniem logiki rozmytej

Słowa kluczowe: obiekty zabytkowe, logika rozmyta, metoda wizualna, ocena stanu technicznego

Streszczenie:

Obiekty budowlane trzeba chronić nie tylko na etapie ich powstawania, ale także podczas eksploatacji. Szczególną uwagę należy zwrócić na obiekty wpisane na listę zabytków. Ustawa o ochronie zabytków i opiece nad zabytkami podaje, iż zabytkiem stać się może każdy budynek, który ma znaczenie dla historii i nauki, przez co powinien być zachowany. Celem niniejszego artykułu było udoskonalenie metody wizualnej oceny stanu technicznego obiektów zabytkowych z wykorzystaniem logiki rozmytej. Udoskonalona metoda ma ułatwić porównanie ocen stanu technicznego budynku wykonywanych w określonych w przepisach odstępach czasu, często przez rożne osoby. Badanie przeprowadzano na podstawie ekspertyz technicznych sporządzonych dla pięciu badanych obiektów będących kamienicami wpisanymi do rejestru zabytków. Stosowanie metody wizualnej przewiduje

ocenę poszczególnych elementów obiektu przez eksperta i werbalny opis elementów przy użyciu pięciostopniowej skali. Istotnym ograniczeniem metody wizualnej jest niepewność związana z dokładnymi zakresami dopuszczalnych wartości, ponieważ przedziały te są subiektywne i zależą od opinii oceniającej osoby. Wpływ tego ograniczenia można zmniejszyć za pomocą stosowania logiki rozmytej (Fuzzy Logic). W modelu logiki rozmytej jako zmienne wejściowe wykorzystano oceny stanu technicznego poszczególnych elementów obiektu (konstrukcja podziemna, ściany nośne, stropy, dach, inne elementy) i integralny wskaźnik stanu technicznego całego obiektu zabytkowego obliczony jako wartość wyjściowa.

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