

# FUZZY INFERENCE SYSTEM ASSISTING THE CHOICE OF A VARIANT OF ADAPTATION OF A HISTORICAL BUILDING

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## Abstract

**Background.** The vast majority of historical buildings no longer serve its original function because that function is no longer needed today. This fact is the reason why many of the abandoned monuments are subject to the process of degradation. A chance to extend the life cycle of historical buildings is their reuse, which is made possible thanks to adapting these facilities to perform new functions. Polish regulations lack a comprehensive, multi-criteria approach to the selection of variants of adaptation of historical buildings despite the practical needs in this area.

**Research aims.** Fuzzy inference system assisting the choice of a variant of adaptation of historical buildings presented in this article meets the above requirements.

**Methodology.** In the analysis, an expert inference system has been developed on the basis of inference rules database by taking into account the fuzzy logic.

**Key findings.** The developed expert fuzzy inference system is designed primarily for decision-makers from the so-called public sector. The choice made by the above mentioned concerning the use of a historical building will result not only from the analysis of expenditures that need to be incurred for the process of adaptation, but also from the benefits which stem from the idea of sustainable development that can be achieved at the same time.

**Keywords:** historical building, conversion options, sustainable development, fuzzy logic.

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## INTRODUCTION AND BACKGROUND

According to the Act of 23<sup>rd</sup> July, 2003 on the protection of monuments and the guardianship of monuments (Journal of Laws of the Republic of Poland of 17<sup>th</sup> September, 2003), a monument is a real estate or a movable, their parts or complexes, being the work of a human being, or connected with their activity, and constituting a testimony of the past epoch or event, the preservation of which is in the social interest because of historical, artistic, or scientific value.

Most historical buildings, erected in the past, no longer serve their original functions as the development of civilization caused that the needs and ways to satisfy them have substantially changed. Consequently, many of the abandoned monuments are subject to the process of degradation. An opportunity to improve the situation is the reuse of historical buildings after their adaption to perform functions which are different than the ones that they have served until now (Szymgina, 2009; Strzelecka, 2011, pp. 661–668; Szymgina, 2012; Wrańska & Jarocka-Mikrut, 2013, pp. 271–278; Śladowski & Radziszewska-Zielina, 2014, pp. 78–89).

The process of prolonging the life cycle of historical buildings linked with the change in their use not only generates benefits for the investors (e.g. good location, attractive look, advantageous purchase of the real estate), but also is a chance to preserve the historical substance for future generations. Forms of adaptation and modernisation transformations vary depending on the size of structures, their technical condition and cultural values, as well as the characteristics resulting from their primary function (functional and spatial structure, material and structural characteristics, location and characteristics of the environment). Selection of the variant of adaptation of a neglected historical building requires identification of tangible and intangible value of the structure and determination of the relationship between properties of the building and its adaptation forms, possibility to preserve its cultural values, investor's preferences, and restrictions concerning the conservation.

Therefore, the choice of the variant to adapt a historical building creates a problematic situation, in which making the decision on the method of adaptation of the abandoned historical building will result from the decision-making process. In this process, the entity that is

the decision-maker, being in a particular decision situation, faces the necessity to choose the best variant of adaptation from many options, taking into account the adapted selection criteria (Śladowski & Radziszewska-Zielina, 2014, pp. 45–50).

The right approach in the decision-making process is an attempt of synthetic description of the decision problem in the form of a decision model, the analysis of which will allow the decision-maker to make the best choices within the criteria adopted (Kapliński, 2007).

A few decision-making models on the choice of a variant of construction works adaptation have been developed in the literature concerning the subject (Hsueh, Lee, & Chen, 2013; Zavadskas & Antucheviciene, 2006, 2007; Wang & Zeng, 2010), but only the last one is relevant to historical buildings, specificity of which requires taking into consideration additional criteria related to cultural heritage. However, the multi criteria approach to the problem of the choice of a variant of a historical building adaptation developed by (Wang & Zeng, 2010) does not take into account, during the analysis, the fuzzy nature of data, which specialists certainly face in the initial phase of the decision-making process.

The aim of this article is to propose a complex approach to the choice of a variant of a historical building adaptation in Polish conditions, since there is a practical need for that. Additionally, the decision-making model developed by the authors of this article takes into consideration the necessity of processing inaccurate information related to the process of a historical building adaptation.

Therefore, the authors firstly present the selection criteria and the way of calculating its value for a given variant of a historical building adaptation. Then, basing on the fuzzy inference system, a method following the selection criteria for the evaluation of each of the considered variants will be presented. In the end, as a tool supporting the process of decision-making with regard to the identified problem, a computer implementation of the above-mentioned method will be performed for practical purposes.

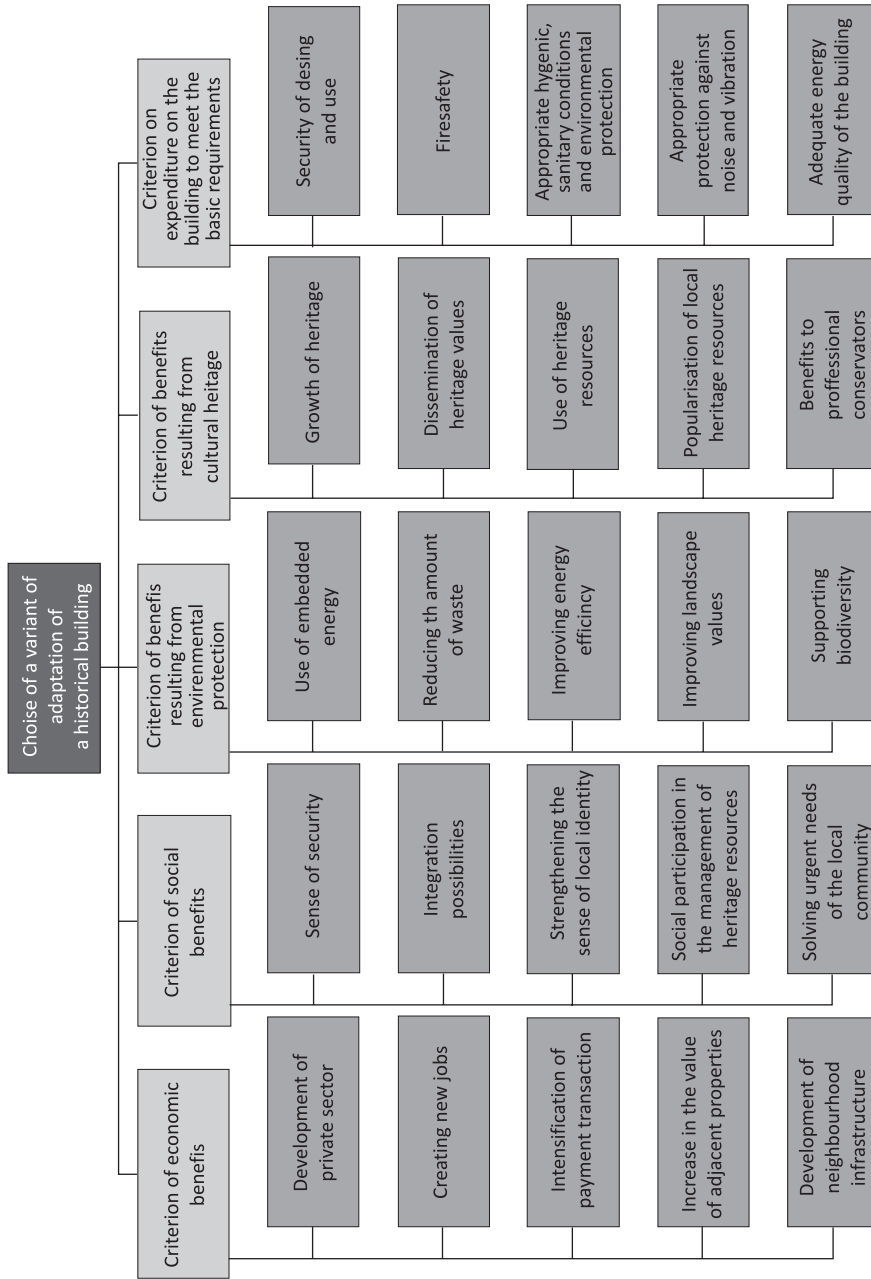
## **Criteria for the choice of a historical building adaptation variant**

The selection of criteria made by the decision-maker will partly depend on his or her preferences as well as on the objective conditions related

to the historical building concerned. Additionally, if the character of building management is connected with the idea of broadly defined regeneration of urban areas, this idea will impose additional selection criteria on the decision-maker, which should be compatible with the principle of sustainable development.

The set of criteria for the selection of a variant of adaptation of historical buildings proposed below is a collection of the so-called benefits of the idea of sustainable development and the criterion of expenditure to be borne in order to meet the basic requirements as listed in Article 5, paragraph 1 of Act of 7<sup>th</sup> July, 1994 Construction law by the adapted building.

- 1) **The economic benefits** derived from the use of neglected and abandoned historical buildings (elimination of vacant buildings) by giving them new operational functions, which can contribute to increasing property value, making the property available for doing business, tourism development, new jobs creation, etc.
- 2) **Social benefits** achieved by strengthening the sense of identity and national integration (society's emotional bond with the historical building as a testimony of the past epoch), providing sense of security through the management of vacant buildings, which are subject to vandalism and uncontrolled settlement, as well as intending them for useful social purposes.
- 3) **The benefits resulting from environmental protection** are made possible by extending the life cycle of the building substance of the historical building. The reduction of construction waste material, energy consumption, and emission of harmful substances constitute tangible benefits which would not be achieved through erection of a new building structure. The protection of the environment is also affected by the potential to improve the energy efficiency of a historical building at the time of its later use.
- 4) **The benefits resulting from protection of cultural heritage** being the result of the preservation and restoration of old cultural features of the historical building and their popularisation. Additional benefit factors for cultural heritage include cognitive values associated with the process of restoration of historical buildings that translate into gaining greater knowledge about the structure and increasing conservation experience.
- 5) **The criterion of expenditure on the building to meet the basic requirements** related to the safety of construction and



**Figure 1.** The criteria and factors in choosing a variant of adaptation of historic buildings

Source: own work.

use, fire safety, appropriate hygienic, sanitary and environmental protection conditions, adequate protection against noise and vibrations, and adequate energy quality of the building. The significance of the above-mentioned requirements should be equal.

Each of the above-mentioned criteria is affected by various factors as shown in Figure 1, the detailed interpretation of which can be found in the works (Affelt, 2009; Śladowski & Radziszewska-Zielina, 2014, pp. 153–164). It should be noted that the defined factors of each of the mentioned criteria are in fact one set of information inaccurate in its nature.

## METHOD

### **The proposition of an assessment method of a variant of adaptation of a historical building**

The usual way of making a decision concerning the choice of a variant of a historical building adaptation in Polish conditions is not analytical but autocratic in nature, which does not always lead to sound choices in terms of the mentioned criteria.

Therefore, attention is drawn to the need to develop effective methods based on fuzzy logic to assess the problem to enable the development, processing, and analysis of inaccurate information, which experts are dealing with in the phase of definition and evaluation of the proposed variants of adaptation of historical buildings. Additionally, uncertainty and imprecision result in the disparity in the opinions of experts. Taking into consideration the fact that the complexity and precision occur in inverse relation (Chojean & Lęski, 2001), a qualitative assessment of the variants of adaptation in the light of the above-mentioned criteria is proposed.

Accordingly, an expert system supporting the decision-making process has been developed for the selection of the variant of historical building management. The study was carried out in the framework of the project “SPIN – Model of Innovation Transfer in Malopolska Region” within the European Social Fund – Human Capital Operational Programme.

The expert system developed has been handed over to an interested company as a decision-making support tool. In the subsequent chapters

the authors of this article demonstrate how the above-mentioned system works.

## Determination of criteria values for a given variant of adaptation of a historical building

To assess the impact of factors on particular criteria the authors of the article use a method of pseudo-fuzzy scaling, which is used to assess the importance of factors affecting the assessment of a given criterion (Urbański, 2001, 2003; Bucoń, 2013). A linguistic grading scale and the corresponding five-point scale will be used for an expert assessment of the factors of a given criterion as shown in Table 1. Specialists taking part in the evaluation should demonstrate interdisciplinary knowledge and they should be experienced in regard to the analysed problem.

Analysing factor  $i$  within the criterion  $j$ , the experts attribute to it one of the five linguistic grades, which transformed into point-base grading scale indicate the grade of  $O_{ij}$ .

Thus, the final value of each criterion for a given variant of adaptation of a historical building can be determined as the weighted average expressed as follows:

$$O_{K_j} = \sum_{i=1}^n w_{ij}^g O_{ij}$$

$$i = 1,2,3,4,5 \quad j = 1$$

where:  $O_{K_j}$  is the assessment of the criterion  $j$  of a given variant,  $w_{ij}^g$  is the total weight of the factor of the criterion  $j$ ,  $O_{ij}$  is a point-base grade of the factor  $i$  of the criterion  $j$ , and  $n$  is the number of factors of the criterion  $j$ .

**Table 1.** Linguistic assessments and their corresponding five-point scale

Linguistic assessment	Very high	High	Average	Low	Very low	Absence of a factor
Five-point scale	5	4	3	2	1	0

Source: based on: Bucoń, 2013.

## The assessment of the variant of adaptation of a historical building with the use of the criteria

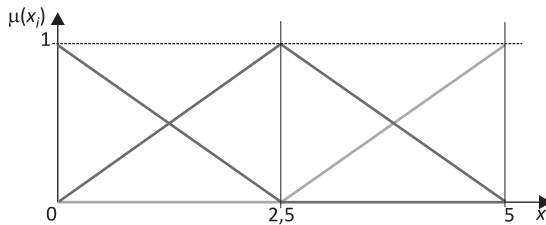
To evaluate the variant of adaptation of a historic building with the use of the above-mentioned criteria, the authors of the article developed an expert fuzzy inference system.

The assessment of variants of adaptation of the considered structure is the result of the three basic processes carried out in the system of inference:

- **fuzzing** (so called fuzzing, i.e. determining the degree of membership in fuzzy sets of input variables (criteria ratings for each variant) as shown in Figure 2;
- **inference** (calculation of the result of membership function through the use of inference operators) over linguistic sphere of output variable according to Figure 3;
- **sharpening** (i.e. calculations of the output acute value (assessment of the variant of adaptation of the historical building).

Terms:

- 0–2.5 low rating (N),
- 0–5.0 average rating (S),
- 2.5–5.0 high rating (W).



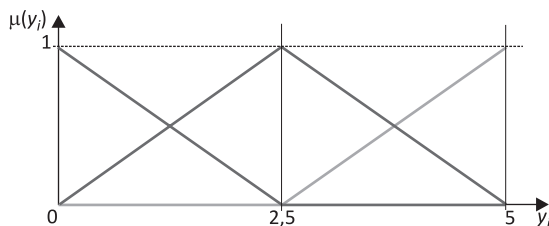
**Figure 2.** Representation of fuzzy input variables

Source: own work.

Terms:

- 0–2.5 unfounded variant (N),
- 0–5.0 justified variant (U),
- 2.5–5.0 preferred variant (P).





**Figure 3.** Representation of fuzzy output variable

Source: own work.

The inference system rule base is called the linguistic model of the inference process and it is based on the knowledge of experts. The rule base defines information about the dependencies that exist between the input variables (premises) and output variable called the conclusion as per Table 2.

**Table 2.** Portions of fuzzy inference rule base

Item No.	PORTIONS OF FUZZY INFERENCE RULE BASE
1	If <b>K1 = W</b> and <b>K2 = N</b> and <b>K3 = W</b> and <b>K4 = W</b> and <b>K5 = S</b> then <b>conclusion = P</b>
...	.....
121	If <b>K1 = S</b> and <b>K2 = N</b> and <b>K3 = S</b> and <b>K4 = S</b> and <b>K5 = N</b> then <b>conclusion = U</b>
...	.....
243	If <b>K1 = N</b> and <b>K2 = W</b> and <b>K3 = N</b> and <b>K4 = N</b> and <b>K5 = W</b> then <b>conclusion = N</b>

Source: own work.

Symbols in the above table are interpreted as follows:

Criteria:

- K1 – Economic benefits,
- K2 – Social benefits,
- K3 – Benefits resulting from environmental protection,
- K4 – Benefits resulting from the protection of cultural heritage,
- K5 – Expenditure on the building to meet the basic requirements.

Evaluation criteria:

- 0–2.5 low rating (N),
- 0–5.0 average rating (S),
- 2.5–5.0 high rating (W).

Conclusions:

- 0–2.5 unfounded variant (N),
- 0–5.0 justified variant (U),
- 2.5–5.0 preferred variant (P).

The inference system developed by the authors is based on the Mamdani model. In the process of creating 243 rules of the inference system, assumptions were made that the most important criterion for evaluation of the variants is the criterion of cultural heritage due to its desirable protection in the process of adaptation of a historical building. Environmental criterion and the criterion of expenditure on the building to meet the basic requirements determine the nature of the conclusions to a lesser extent.

The output variable membership function is the result of carrying out inference operations in the system for each variant of adaptation of a historic building. In order to obtain the final assessment of a given variant of adaptation of a historic building, the fuzzy area of each variable should be sharpened to a specific value. For this purpose, a sharpening operation based on the method of centre of gravity (centre of area) has been used,

$$y^* = y_c = \frac{\int y \cdot \mu(y) dy}{\int \mu(y) dy}$$

where:

$y^* = y_c$  is the acute value of the controller output (result value),

$\mu(y)$  is the resulting membership function for the assessment of variants of adaptation of a historical building,

$y$  is the value of the output variable.

## RESULTS

### **Computer implementation as a tool to assist decision-making on the choice of the variant of adaptation of a historical building**

For the purposes of an efficient decision-making process of the choice of variant of adaptation of a historical building, a tool was developed that has been shared with an interested consulting company. Figures 4–7 show the way in which the system works on the example of a particular decision problem concerning the choice of the variant of adaptation of a post-industrial historical building in the city of

Olsztyn. As part of the decision-making process variant number 1 of adaptation for an office was considered, as well as variant number 2 of performing a museum of technology. As a result of the analysis, conducted with the use of the aforementioned software, it can be seen that the variant of adapting the historical building for the office was rated higher (Figures 6–7), which means that it is preferable in terms of the analysed criteria. When analysing ratings of the variants for each criterion, it can be noticed that, when compared to the alternative variant, the functioning of the building as the office entails significant economic and social benefits. Environmental protection related benefits as well as cultural heritage benefits are at a similar level for both buildings. Though, when choosing the variant of adapting the historical building for the office, one must be aware of higher costs that need to be incurred due to its implementation.

One must pay attention to the fact that the proposed selection criteria and its factors are of universal nature, and they may be used for choosing a variant of a historical building adaptation in other regions of the country as well as abroad. In each case, as a result of an evaluation made by specialists, importance of the factors may change, and consequently, importance of the selection criteria, which are going to conform to the circumstances and character of the choice, may be changed.

## **DISCUSSION & CONCLUSIONS**

The developed inference system, based on fuzzy logic, assisting the decision-making process on the choice of a variant of historical building adaptation is of universal character and can be used in different regions of the country and abroad for solving the aforementioned selection problems. The fuzzy inference system has not been used yet for choosing a variant of a historical building adaptation based on the factors and selection criteria typical of this problem. Introducing fuzzy logic allows to develop, process, and analyse inaccurate data, which specialists face during the phase of definition and evaluation of the proposed variants of adaptation of historical buildings. The developed fuzzy inference system aggregates specialists' opinions, for the dubiousness and inaccuracy of the processed data may result in different opinions.

System wspomaganie wyboru wariantu adaptacji budynku zażytkowego: C:\Users\Grzegorz\Desktop\Wsp\Uzzy\Dame\Wzorzec\_UZ\_1.xlsx

Wykonaj obliczenia

Warianty adaptacji budynku zażytkowego | Analiza wag subkryteriów | Analiza z zastosowaniem logiki rozmytej

Wybór kryterium

**Korzyści wynikające z ochrony środowiska**

Ocena wag subkryteriów

Ekspert	Wykorzystanie energii wbudowanej	Zmniejszenie ilości odpadów	Poprawa wydajności energetycznej	Poprawa walorów krajozrazowych	Wspornaganie bioróżnorodności
1	D	D	BD	S/M	M
2	BD	BD	BD/D	S	M
3	D	D	BD/D	S/M	M
4	D	D	BD/D	S	M
5	D	D	BD/D	S/M	M
6	D	D	BD/D	S	M
7	D	D	BD/D	S/M	M
8	D	D	D	S/M	M
9	D	D	D	S	M
10	BD/D	BD	D	S	M
Ocena wariantów adaptacji budynku zażytkowego dla poszczególnych subkryteriów					
Warianty adaptacji budynku zażytkowego					
War 1	4	4	3	4	3
War 2	3,3	3,2	4,1	4,7	2,4
Poprawa walorów krajozrazowych					
Wspornaganie bioróżnorodności					

**Figure 4.** Linguistic assessment of 10 experts concerning the significance of factors to calculate their importance within criterion of environmental protection and assess these factors

Source: own work.

System wspomaganie wyboru wariantu adaptacji | Analiza wag subkryteriów | Analiza z zastosowaniem logiki rozmytej

Warianty adaptacji budynku zabytkowego | Wybór kryterium

**Korzyści wynikające z ochrony środowiska**

Stopnie przynależności opinii ekspertów

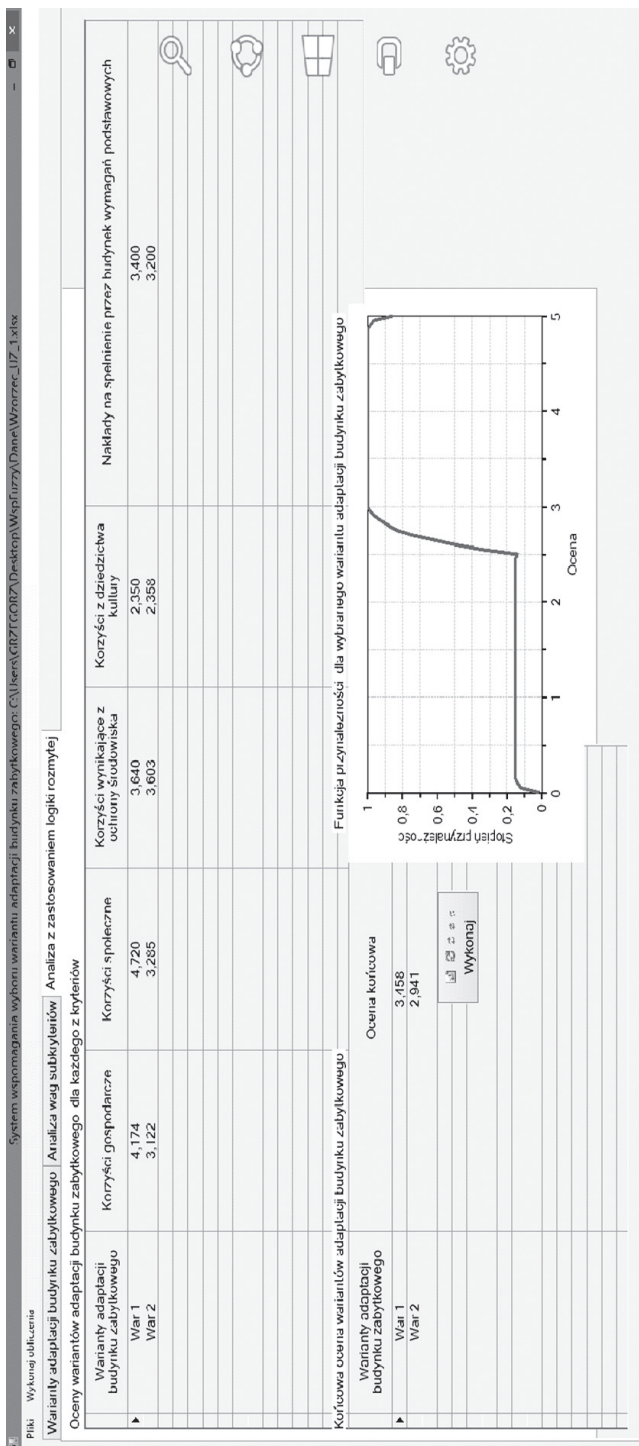
Oceny	Wykorzystanie energii wbudowanej	Zmniejszenie ilości odpadów	Poprawa wydajności energetycznej	Poprawa walorów krajobrazowych	Wspomaganie bioróżnorodności
▶ DIM	0,000	0,000	0,000	0,000	0,000
M/BM	0,000	0,000	0,000	0,000	0,000
M	0,000	0,000	0,000	0,000	1,000
S/M	0,000	0,000	0,000	0,500	0,000
S	0,000	0,000	0,000	0,500	0,000
D/S	0,000	0,000	0,000	0,000	0,000
IJ	0,800	0,800	0,300	0,000	0,000
BD/D	0,100	0,000	0,600	0,000	0,000
BD	0,100	0,200	0,100	0,000	0,000

Waga globalna dla subkryteriów

Wagi	Wykorzystanie energii wbudowanej	Zmniejszenie ilości odpadów	Poprawa wydajności energetycznej	Poprawa walorów krajobrazowych	Wspomaganie bioróżnorodności
▶	0,243	0,247	0,200	0,150	0,100

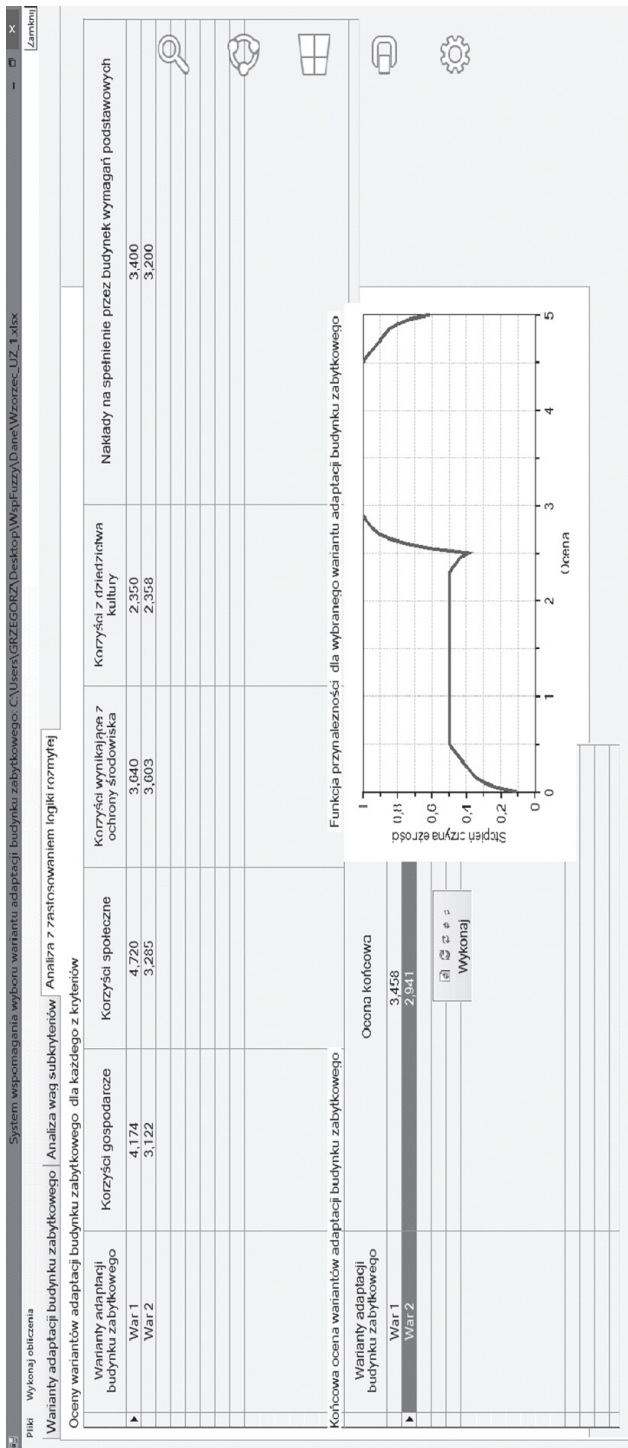
Figure 5. Degrees of membership of expert opinions for each of the factors and calculating importance of these factors for the criterion of the benefits resulting from environmental protection

Source: own work.



**Figure 6.** The value of the criteria for a given variant and the final evaluation of variant 1 in light of all the criteria with a graph showing the resulting membership function

Source: own work.



**Figure 7.** The value of the criteria for a given variant and the final evaluation of the variant 2 in light of all the criteria with a graph showing the resulting membership function

Source: own work.

The nature of the proposed criteria for the selection of a variant of adaptation of historical buildings suggests using the system primarily by the decision-makers from the so-called public sector. The choice made by the above mentioned concerning the use of the historical building will result not only from the analysis of expenditures that need to be incurred for the process of adaptation, but also from the benefits which stem from the idea of sustainable development that can be achieved at the same time.

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## SYSTEM ROZMYTEGO WNIOSKOWANIA WSPOMAGAJĄCY WYBÓR WARIANTU ADAPTACJI BUDYNKÓW ZABYTKOWYCH

### Abstrakt

**Tło badań.** Zdecydowana większość budynków zabytkowych nie pełni już swoich pierwotnych funkcji, ponieważ funkcje te nie są już dzisiaj potrzebne. Fakt ten powoduje, że wiele opuszczonych zabytków ulega procesom degradacji. Szansą na wydłużenie cyklu życia obiektów zabytkowych jest ponowne ich użytkowanie, możliwe w wyniku adaptacji tych obiektów do nowych funkcji. W polskich warunkach brakuje kompleksowego, wielokryterialnego podejścia do wyboru wariantów adaptacji budynków zabytkowych pomimo istniejących praktycznych potrzeb w tym zakresie.

**Cel badań.** Zaprezentowany w niniejszym artykule system rozmytego wnioskowania wspomagający wybór wariantu adaptacji budynków zabytkowych wychodzi naprzeciw powyższym potrzebom.

**Metodologia.** W analizie opracowano ekspercki system wnioskowania na podstawie bazy reguł z uwzględnieniem logiki rozmytej.

**Kluczowe wnioski.** Opracowany ekspercki system rozmytego wnioskowania przeznaczony jest przede wszystkim dla decydentów z tak zwanego sektora publicznego. Wybór dokonany przez owych decydentów dotyczący sposobu zagospodarowania budynku zabytkowego będzie wynikać nie tylko z analizy nakładów, jakie trzeba ponieść na proces jego adaptacji, ale także z korzyści wynikających z idei zrównoważonego rozwoju, jakie można przy tym osiągnąć.

**Słowa kluczowe:** budynek zabytkowy, warianty adaptacji, zrównoważony rozwój, logika rozmyta.