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Using Fuzzy Logic Based Decision Support Systems for New Function Selection in Structures

Didem BARAN ERGÜL [1*], Ayşe Berika VAROL MALKOÇOĞLU [2]
Seden ACUN ÖZGÜNLER [3]

ORCID 1: 0000-0001-5705-8885
ORCID 2: 0000-0003-1856-9636
ORCID 3: 0000-0001-5975-5115
[1] *Beykoz University, Department of Interior Design, 34810, İstanbul, Türkiye.*
[2] *Beykoz University, Department of Computer Programming, 34810, İstanbul, Türkiye.*
[3] *Istanbul Technical University, Department of Architecture, 34367, İstanbul, Türkiye.*
**** e-mail:** didembaranergul.@beykoz.edu.tr*

Abstract

These buildings, which function as important documents for the period in which they were built, and which have managed to preserve their original qualities, have been abandoned as a result of various some factors and have lose their functionality. It is very important to continue to use these original structures, which have since lost their functionality, with re-functioning as opposed to a passive conservation approach. Architectural decision support systems, used to create a solution mechanism can assist architects in deciding on the most appropriate function option for building by systematizing the relationship between spatial analysis of the existing building stock and functional expectations. Accordingly, the results were observed by using fuzzy logic method in order to determine the most suitable function option before the design and construction phases for reuse of the building were started.

Keywords: *Refunctioning, adaptation, decision support systems, fuzzy logic.*

Yapılarda Yeni İşlev Seçimi İçin Bulanık Mantık Tabanlı Karar Destek Sistemlerinin Kullanımı

Öz

Yapıldıkları döneme dair önemli bir belge niteliği taşıyan, özgün niteliklerini korumayı başarabilmiş yapılar, kimi faktörler neticesinde terkedilmekte ve işlevlerini yitirmektedir. İşlevini kaybetmiş özgün yapıların, pasif bir koruma anlayışı yerine, yeniden işlevlendirme ile kullanılmaya devam edilmesi oldukça önemlidir. Bu durum, yapıların sürdürülebilirliğinin sağlanmasının yanında ekonomik, ekolojik ve toplumsal faydaları da beraberinde getirmektedir. Yapı için uygun işlev seçeneğinin belirlenebilmesi adına, mevcut yapı stokunun mekânsal analizleri ile fonksiyona dair beklentiler arasındaki ilişkiyi sistematize eden ve tasarımcılara karar vermede yardımcı olan karar destek sistemlerinden faydalanılabilir. Bu sistemlerden, tasarım ve yapım aşamalarına geçilmeden önce, yapının yeniden kullanım amacına yönelik en uygun işlev seçeneğinin belirlenebilmesi için kantitatif bir değer şeklinde sistematik ve rasyonel bir yöntemle sonuç üretmesi beklenir. Bu sonuçların üretilmesi için çalışmada bulanık mantık yöntemi seçilerek sonuçlar gözlemlenmiştir.

Anahtar Kelimeler: *Yeniden işlevlendirme, adaptasyon, karar destek sistemleri, bulanık mantık.*

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1. Introduction

Historical environments refer to the ruins and settlements that have survived from past periods to the present day. These ruins and settlements, which take part in the transmission of such information in the historical process, are of vital importance in ensuring the continuity of culture. A lot of unwritten information about the past periods reaches the present day through structures. The structures in the historical rural settlements, on the other hand, are examples of architecture without architects. These structures are also important because they are a means of transmitting how sustainable architecture should be in terms of criteria, such as materials, construction techniques, plan diagrams, and adaptation to the topography, which have occurred as a result of the experience gained over the years. However, rural settlements are gradually losing population because the people of the region leave these settlements due to some reasons such as economic difficulties encountered in rural areas, security, education, and health; thus, the structures that make up the settlement tissue remain unclaimed over time. In order to maintain the existence of rural dwellings, which are one of the most important elements that constitute the rural fabric and which have become open to external influences because they remain derelict and dysfunctional and are facing the danger of extinction, different conservation approaches have been developed at different periods on the scale of settlement. Investigating the adaptive reuse of the settlement, and if possible reuse of it is one of these conservation approaches. In this context, four different options can be mentioned in order to reuse rural settlements: museumization, tourism, resettlement, and reforestation (Güler, 2016).

Following the identification of the appropriate revitalization and adaptive reuse option for the current settlement, it is inevitable that many of the structures shaped according to the time to which they belong will be loaded with a new function other than their original function. The fact that the structures maintain their economic life with their new function instead of a passive conservation understanding brings with it ecological and social benefits as well as cultural benefits. However, in order to ensure the sustainability of the structures in their original state as much as possible, the existing structure and the spatial requirements of the new function must be adaptable. In reuse, to be able to decide on the function option that will serve the revitalization option at the settlement scale, first of all, it is necessary to conduct spatial and environmental analyzes and, accordingly, the right choice of functions should be realized. A successful design and implementation can only be possible after this step. In the process of changing the function of single historical buildings, the intervention method can be determined by comprehensively analyzing the environmental and architectural features of the structure. But especially on a settlement basis, to be able to determine the adaptability capacity of the existing building stock and possible suitable functions, and to be able to provide decision support for the design and implementation stages, the selection of functions should be carried out systematically and rationally. At this point, support systems for decision makers can be developed for structure transformation by using multi-input models. It is thought that in this kind of multi-input design problem, a model that helps to make the right decision can support architects to decide on the most suitable function option for any structure by making spatial and environmental analyses of existing structures and systematizing the relationship between expectations about function. In particular, a decision support system based on fuzzy logic comes to the fore as a method that can be preferred in such models in cases where the most appropriate one among the adaptation options is evaluated instead of the exact results, such as determining the function.

Based on the above-mentioned considerations, this study, it was aimed to create a fuzzy logic-based decision support system by systematizing the relationship between existing capacity and new functional change demands and to produce decision support in this way.

2. Conceptual Context

In this section of the study, the concepts of “re-functionalization” and “fuzzy logic”, which constitute the subheadings of the research, are discussed in line with the limitations of the research, and general information about reuse and functional adaptation in structures is provided.

2.1. Re-functionalization

When it is aimed to protect an existing structure, various methods can be applied. *Re-functionalization* is one of these methods. It can be expressed as an intervention to extend the life of the structure by adapting it to a need that is different from its function at the first construction time (Yıldırım & Turan, 2012). Structures bearing the traces of the period in which they were built become unable to meet the requirements expected from them over time as a result of changes occurring in the structure and identity of society. Especially about the structures in settlements that have lost their population as a result of various factors, an overall dis-functionalization can be talked about. Structures that are out of function become structurally unusable over time by becoming vulnerable to the corrosive effects of external environmental conditions. Giving a new function to the civil architecture samples, which have the nature of historical documents, by preserving their structural features with certain principles ensures the transfer of memory and culture in addition to providing a significant amount of energy and resource conservation. When the sustainability of the existing structure is aimed at a new function, it is inevitable to experience a change and transformation in the existing space layout with a new program. In this process of change and transformation, which can be defined as adaptation in reuse, the adaptation of the structure in a way that can serve the new function and the preservation of its original identity should be considered in combination. Sustainable adaptation can only be possible in this way. The first step to be taken for this is to select the right function for the structure and perform a successful design and implementation (Aksoya & Aydın, 2015).

The sustainability and habitability of the structure depend on the adaptability of the existing structure to the requirements of the new function. The adaptation of the function to be given to the structure with the old space means that the context and spatial possibilities overlap (Büyükarslan & Güney, 2013; Arpacıoğlu, Çalışkan, Şahin, & Ödevci, 2020; Kutlu & Ergün, 2021,). Therefore, the spatial requirements of the new function should be questioned and its compliance with the structure should be well analyzed. For this, it is relatively easier to perform detailed analysis studies based on a singular structure. However, a preliminary decision support system will inevitably be needed to be able to make decisions for a large number of structures on a settlement basis.

2.2. Fuzzy Logic

Fuzzy logic is a concept that was put forward by the mathematician Zadeh in 1965. Fuzzy logic, which is a rule-based algorithm, also represents uncertainties in contrast to classical logic. This logic type was designed inspired by the human decision-making mechanism in changing environmental conditions. With this feature, it has been used for a long time in many decision-support models in the field of architecture (Baran Ergül, Varol Malkoçoğlu, & Acun Özgünler, 2022). In Fuzzy Logic, the main idea is to be able to generate other probabilities that fall between the values of 0 or 1. In classical logic, the result of a given proposition is either true or false. In fuzzy logic, on the other hand, intermediate values can be generated to represent uncertainties as an addition to the results of "0-1", "there is-there is not", and "yes-no" (Zadeh, 1965). The fuzzy logic system is based on the concept of a set and consists of three basic parts. These parts are as follows:

1. Fuzzification
2. Rule-based inference
3. Defuzzification

In fuzzification, the degrees of membership (membership value) corresponding to the value of the input variables are determined. These degrees help to determine how much an element belongs to that set or not. The function that shows the “degrees of belonging” of the set elements is called the membership function. The start and end values are included in this function. In the function (1) below, X represents the universal definition set, A represents the fuzzy set, x represents the cluster elements, and μ_A represents the membership degrees of the x cluster elements.

$$\mu_A(x): X \rightarrow [0,1] \quad \begin{cases} \mu_A(x) = 0; \text{ the element x is not included in the set A.} \\ \mu_A(x) = 1; \text{ the element x is fully included in the set A.} \\ 0 < \mu_A(x) < 1; \text{ the element x is a part of the set A.} \end{cases} \tag{1}$$

In rule-based inference, verbal rules are determined by experts using the degrees of membership coming from the fuzzification unit, and fuzzy results are obtained. That is, the result of the inference is a fuzzy set.

In defuzzification, in order for these fuzzy sets to make sense in the real world, the obtained fuzzy information is converted into information used in the real world. These operations can be performed through various mathematical operations, such as the center of gravity, weighted average, and center of area methods (Ödük, 2019).

With fuzzy logic, solutions can be produced for complex problems that classical logic cannot solve, and uncertainties that are also inherent in human nature can be represented. Thus, more objective results can be obtained by distinguishing between elements that are members of the same set.

2.3. Reuse and Functional Adaptation in Structures

The ability of unused structures to continue their service with their new function is primarily related to many issues, such as the compatibility of the function to be installed with the spatial layout of the structure (spatial adaptation) and its location in the settlement layout (environmental adaptation) (Aksoya & Aydın, 2015). In this context, it is possible to consider the adaptation of an old structure for the new function under two headings: “spatial functional adaptation" and “environmental functional adaptation”.

2.3.1. Spatial functional adaptation

In re-functionalized buildings, spatial functional adaptation is determined by identifying the spatial requirements and analyzing how the use and purpose of use are affected. Since identifying the spatial requirements related to the function and measuring the adaptation of the existing structure with these requirements will also shape the future of the structure to be re-functionalized, it is very important for the sustainability of its function.

The following criteria determine the functional performance of the space in the structures that are considered to be re-functionalized:

- *Spatial dimension* (the compliance of dimensional characteristics for the intended use of the new function and for users),
- *Circulation/circulation* (compliance of the existing circulation scheme of the structure with the functional relations of the new function),
- *Zoning/communication/workflow* (being able to meet some of the possibilities of the new function, such as service),
- *Flexibility / change* (adaptation of the current state of the structure to the needs of the new function, adaptation of the structure to the current situation, functional adaptation and flexibility of the reinforcement elements)
- Use / specialization (being a harmony between the original function of the structure and its reuse)”

2.3.2. Environmental functional adaptation

The re-functionalized structures continue to exist and are protected if they benefit the environment and the people of the region and if they can respond to environmental needs. Thanks to the re-functionalizing, it is possible to contribute to the environment by taking advantage of the existing structures, the sustainability of the settlement is supported, and it is ensured that future generations benefit from these resources (Dyllick & Hockerts, 2002; Aydın & Yaldız, 2010). In this context, the environmental performance of the place can be evaluated through creating a benchmark in the environment (emphasizing the cultural and historical value of the region, being a means of description in the environment in which it is located and accepting a new function in the city as a whole) and symbolic value (revealing the urban symbolic value, aesthetic value, document value of the building) (Yaldız, 2013). In addition, the location of the structure within the settlement, reachability as pedestrians and vehicles, accessibility for different users, or adaptability to the accessibility nature can be considered within the environmental functional adaptation criteria.

The reuse and functional adaptation table for the structures created in accordance with the specified performance criteria is shown in Figure 1. In the study, these adaptation criteria were analyzed, and in order to determine the ranges for all criteria, values were determined based on literature research.

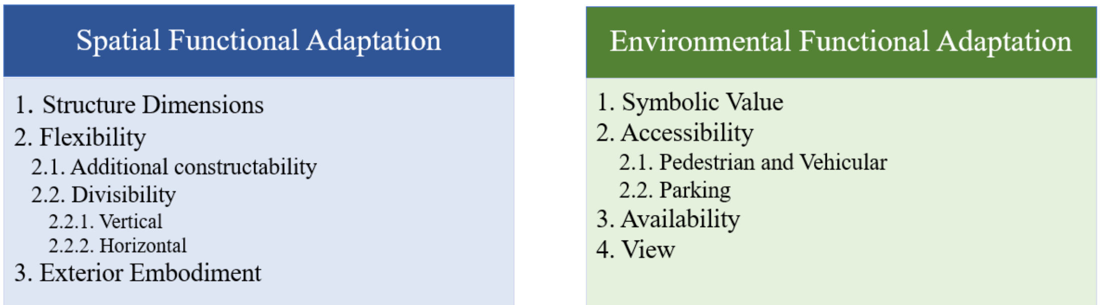

Figure 1. Reuse and functional adaptation table for structures (Baran Ergül, 2022)

3. Materials and Methods

Benefiting from decision support systems for re-functionalizing an existing building stock in a way that will serve the re-evaluation decision taken on a settlement basis will increase the efficiency of the design and implementation processes. Therefore, the study focused on the development of a fuzzy logic-based model for the selection of new functions in structures. The main reason for choosing a fuzzy logic algorithm in the model is that fuzzy logic can produce results that are not sharp and have high accuracy in uncertain ambient conditions. For this reason, it allows space for intuitiveness due to the nature of the design. Fuzzy logic can transform the design into a more subjective structure in a multi-layered decision process such as the selection of new functions in structures by ensuring that the designers' point of view and the variable environmental conditions in which the design is carried out are also included in the decision mechanism.

In this context, the fuzzy logic algorithm was used in the MATLAB environment for the purpose of creating a model for the selection of new functions in structures. The starting and ending ranges of the membership functions were determined in accordance with the expert opinion. The Mamdani controller was used. As shown in Figure 2, there are 9 inputs and 4 outputs in the model. Each input and output value consists of continuous sets with a certain range.

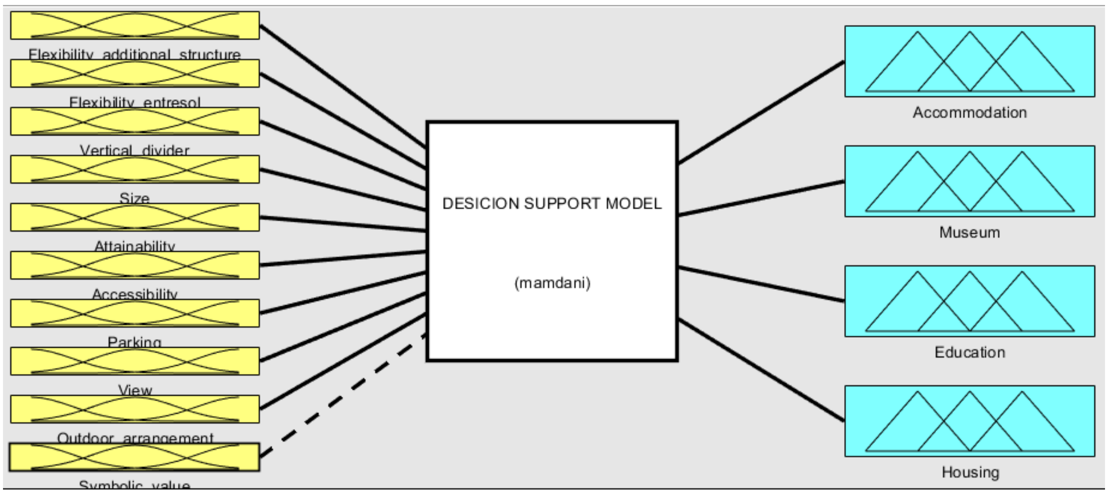

Figure 2. Fuzzy logic-based decision support model (Varol Malkoçoğlu, 2022)

The entry parameters were determined based on the spatial and environmental adaptation criteria. These criteria were concretized and evaluated in order to be included in the algorithm. For example, the horizontal divisibility criterion included in the flexibility criterion was evaluated based on the floor height. In addition, flexibility, which allows changes to the plan according to the new function, was included in the algorithm depending on the vertical divisibility axle range. The parking criteria included in the functional adaptation parameter in terms of environmental point of view were numbered taking into account whether there were enough parking lots in and around the structure, whether the structure had a relationship with the surrounding parking lots, or whether there is an urban place that can be considered as a parking lot. The target values related to all these criteria were obtained from the literature review and the opinions emerging in the focus group study. The range values determined for the mentioned properties are shown in Table 1 and Table 2.

Table 1. Membership functions belonging to each input property

Input Parameters	Degree of Membership		
	Name	**Parameters**	**Types**
Flexibility_additional_structure	None	[0 0 0]	trimf
	Small	[0 1 2]	trimf
	Medium	[1 2 3]	trimf
	Large	[2 3]	smf
Flexibilit _entresol	None	[2 3]	zmf
	Small	[2.5 3.25 4]	trimf
	Medium	[3.5 4.25 5]	trimf
	Large	[4.5 6]	smf
Vertical_divider	Small	[1 2.25 3.5]	trimf
	Medium	[2.75 4 5.25]	trimf
	Large	[4.5 6]	smf
Size	Small	[1 75 150]	trimf
	Medium	[120 235 350]	trimf
	Large	[300 500]	smf
Attainability	Small	[0 1 2]	trimf
	Medium	[1 2 3]	trimf
	Large	[2 4]	smf
Accessibility	None	[0 0 0]	trimf
	Small	[0 1 2]	trimf
	Medium	[1 2 3]	trimf
	Large	[2 3]	smf
Parking	None	[0 1]	zmf
	Small	[0.5 1 1.5]	trimf
	Medium	[1.5 2 2.5]	trimf
	Large	[2 3]	smf
View	Small	[1 2]	zmf
	Medium	[1.5 2 2.5]	trimf
	Large	[2 3]	smf
Outdoor_arrangment	None	[0 1]	zmf
	Small	[0.5 1 1.5]	trimf
	Medium	[1.5 2 2.5]	trimf
	Large	[2 3]	smf
Symbolic_value	None	[0 0 0]	trimf
	Small	[0 1 2]	trimf
	Medium	[1 2 3]	trimf
	Large	[2 4]	smf

Table 2. Membership functions belonging to each output property

Output Parameters	Degree of Membership		
	Name	Parameters	Types
Accommodation	Small	[0 0 40]	trimf
	Medium	[20 50 80]	trimf
	Large	[60 100 100]	trimf
Museum	Small	[0 0 40]	trimf
	Medium	[20 50 80]	trimf
	Large	[60 100 100]	trimf
Education	Small	[0 0 40]	trimf
	Medium	[20 50 80]	trimf
	Large	[60 100 100]	trimf
Housing	Small	[0 0 40]	trimf
	Medium	[20 50 80]	trimf
	Large	[60 100 100]	trimf

In the next step of the creation of the model, the structure types were determined. In the re-evaluation and selection of structures, the possibilities of new functions are quite numerous. However, in this study, re-evaluation alternatives were focused on for settlements of a rural nature, especially those that had been abandoned as a result of various factors, and the structure types that can serve options such as musealization, tourism, resettlement, and forestation were tried to be determined (Güler, 2016). In the study, the structure types were limited to four different types as accommodation service units, educational buildings, museums, and residences in a way that can serve all the options of musealization, tourism, and resettlement. Of course, in different studies, it is possible that different structure types that serve different main functions may also be included in the new function options.

At the stage after determining the types of structures, their interaction with the spatial and environmental adaptation parameters determined at the previous stage was carried out and they are shown in Table 3. The interaction values in this table were organized based on the data obtained from the literature review, and they indicate the importance of the criteria for the mentioned structure types that have four different functions. For example, structural dimensions are most important for accommodation service units in order to implement the correct plan design. Whereas reachability is an important criterion for accommodation service units, educational structures, and museum options in terms of the sustainability of the function, it is of less importance for the housing option. Whether the structure has a symbolic value or not is evaluated as an important criterion for choosing the museum function.

Table 3. Interaction with spatial and environmental adaptation parameters (Baran Ergül, 2022)

Accommodation		Education		Museum		Housing	
Structure Dimensions	high	Structure Dimensions	medium	Structure Dimensions	medium	Structure Dimensions	less
Flexibility/ Additional Constructability	high	Flexibility/ Additional Constructability	medium	Flexibility/ Additional Constructability	less	Flexibility/ Additional Constructability	none
Flexibility/ Divisibility/Vertical	medium	Flexibility/ Divisibility/Vertical	medium	Flexibility/ Divisibility/Vertical	less	Flexibility/ Divisibility/Vertical	none
Flexibility/ Divisibility/Horizontal	high	Flexibility/ Divisibility/Horizontal	medium	Flexibility/ Divisibility/Horizontal	medium	Flexibility/ Divisibility/Horizontal	less
Exterior Embodiment	medium	Exterior Embodiment	high	Exterior Embodiment	none	Exterior Embodiment	less
Symbolic Value	medium	Symbolic Value	medium	Symbolic Value	high	Symbolic Value	none
Accessibility/ Pedestrians and Vehicular	high	Accessibility/ Pedestrians and Vehicular	high	Accessibility/ Pedestrians and Vehicular	high	Accessibility/ Pedestrians and Vehicular	medium
Accessibility/Parking	high	Accessibility/Parking	medium	Accessibility/Parking	high	Accessibility/Parking	medium
Availability	high	Availability	high	Availability	high	Availability	less
View	high	View	medium	View	medium	View	less

In the model, after determining the possible structure types, the functional adaptation parameters that affect the selection of these structure types, and the interaction of these parameters with the structure types, rules were established based on these interaction states.

4. Findings and Discussion

In the fuzzy logic-based decision support system designed within the scope of the study, parameters, ranges of the parameters, and rules were determined by considering the literature review and the focus group. In order to test the resulting model, the results to be produced by the model were observed by taking the sample structure criteria. In this regard, the accuracy and likelihood of the results produced by the model were evaluated using a sample.

With the aim of testing the appropriateness of the decisions made by the fuzzy logic-based decision support system designed for the selection of new functions in structures, the examination of the Vasfi Süsoy House, which is located in the historical vicinity of Tokat and had been re-functionalized and transformed into a Tourism Development and Education center was carried out. The study in question was conducted based on the data obtained in the study titled "A Traditional House that has been Re-Functionalized; Tokat Vasfi Süsoy House" (Akin, Kalınbayrak Ercan, Mumcuoğlu & Yaprak Başaran, 2018). Vasfi Süsoy House was built in 1933 as a residential building in the Topçular Neighborhood of Tokat, which is now declared an urban protected area. The layout features, inward-facing layout, and plan and facade features of the traditional houses in Tokat and Anatolia are also seen in the Vasfi Süsoy House. The facade of the structure, which is in a garden and located on a plot of land that does not have a lot of slopes, is seen in a form leaning against the street. Considering the studies on the spatial performance of the building, and its harmony between the environment and users, the appropriateness of the Tourism Development and Education Center function for the building emerges. From the point of view of spatial and environmental functional adaptation criteria, it is seen that due to the fact that the structure is located in the garden, the outdoor arrangement value is high. The horizontal divisibility values of the structure are low due to additional constructability and floor height. However, especially due to the barn space that is present in its original structure, its vertical divisibility is possible. Although the building has a symbolic value due to the fact that it is located in the urban protected area, it is not a residential building that has taken place in the memory of the city. In addition, due to the fact that it is located within the urban protected area, the parking value was also determined as medium. As can be seen in Figure 3, when the values determined in accordance with the criteria were processed into the model, the model produced the result showing that the structure in question can be transformed into an educational structure by 87%. Based on this, it can be said that the model is able to produce correct decisions.

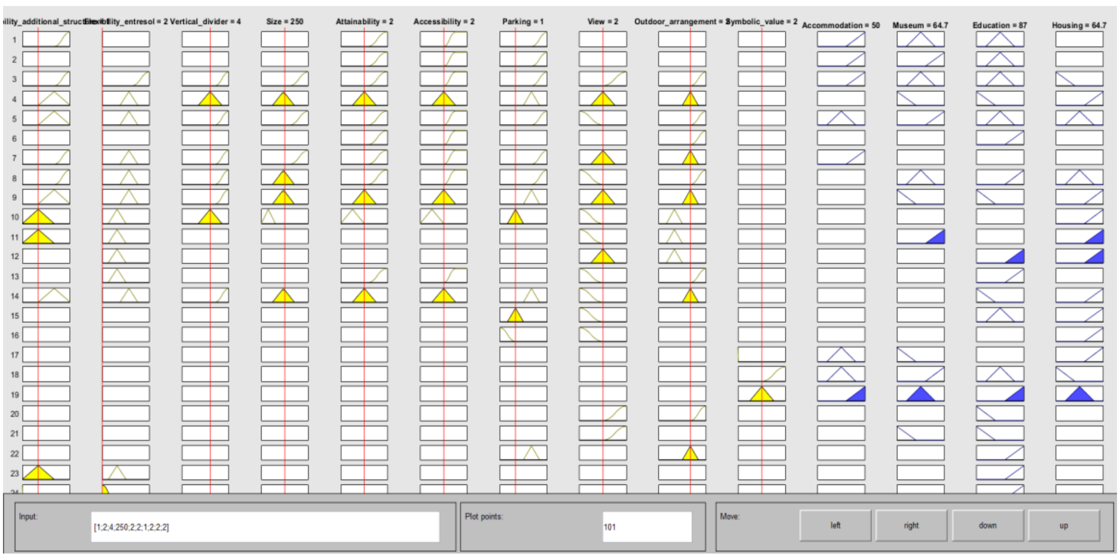

Figure 3. The example performed with the fuzzy logic-based decision support model (Varol Malkoçoğlu, 2022)

5. Conclusion

It is seen that the fuzzy logic-based decision support model, which will be used to decide on a function option that will serve the revitalization option at the settlement scale in reuse, works if the appropriate criteria related to the structures and the rules related to the structure types are determined correctly. But in order for the model to produce healthy decisions, in the documentation studies on the existing building stock, it is very important that spatial and environmental parameters related to the reuse of structures are included as data.

The model designed within the scope of the study has 9 different input features and gives results for 4 different structure types. The number of parameters belonging to the input and output characteristics used in the structure, the range of the parameters, parameter types, and the rules created thanks to these parameters were created as a result of a focus group method and literature review. It is possible to differentiate the number and nature of the determined input and output parameters in such a way as to serve the re-evaluation option, and to include different target-oriented structure types into the model as a result of this. In the decision support system developed for the selection of new functions in structures, more than 20 rules have been determined. It is thought that the number of rules should be increased to define more detailed results.

Finally, the determination of the interaction between the structure types and the functional adaptation parameters, which were determined in this study by literature review and the focus group method, is planned to be carried out by an artificial intelligence-based model in a future study.

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The article complies with national and international research and publication ethics. Ethics Committee approval was not required for the study.

Author Contribution and Conflict of Interest Declaration Information

1st author %40, 2nd author %40 and 3rd author %20 contributed. There is no conflict of interest.

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