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Evaluation Methods of the Structures' Aesthetics – Part II

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Abstract

Main component in the process of deepening a field, the evaluation was also applied to the theme of structures' aesthetics, within the research conducted for the PhD thesis "Study of aesthetics in civil engineering". The discussions were started in the first part of this paper, with: the critique of structural aesthetics, evaluation criteria, modern ways of evaluating the structures and the opportunity to implement a Decision Support System in the process of evaluating the structures, with its synthetic presentation. The present paper, the second part of the research, focuses on the Intelligent Decision Support System using Fuzzy logic, the main fuzzy logic elements involved in such a system and the presentation of our proposal to use fuzzy logic through an application for the aesthetic evaluation of the structures. The last subject has two components, further presented: the one dedicated to the public, as the final beneficiary of the entire process, involving it actively in the assessment process, and the component to further help the decision-maker obtain a fingerprint for a structure, through an application that uses the fuzzy logic.

Rezumat

Componentă principală în procesul de aprofundare a unui domeniu, evaluarea a fost aplicată și asupra temei esteticii structurilor, în cadrul cercertărilor derulate pentru lucrarea de doctorat "Studiu de estetică în inginerie civilă". Discuțiile au început în prima parte a acestei lucrări, referitoare la: critica asupra esteticii structurilor, criterii de evaluare, modalități moderne de evaluare a structurilor și oportunitatea implementării unui Sistem Decizional în procesul de evaluare a structurilor cu prezentarea sintetică a acestuia. Lucrarea de față, a doua parte a studiului, abordează: valorificarea Sistemului Decizional Inteligent cu Logică Fuzzy în evaluarea estetică a structurilor, prezentarea succintă a principalelor elemente de logică fuzzy implicate într-un asemenea sistem și încheie cu o propunere proprie de aplicarea a elementelor prezentate anterior în evaluarea estetică a lucrărilor de structură. Ultimul subiect are două componente: una dedicată publicului, ca fiind beneficiarul final al întregului proces, și componenta care îl ajută pe decident să obțină o amprentă digitală a unei structuri, cu ajutorul unei aplicații care folosește logica fuzzy.

Keywords: structural aesthetics, aesthetics criteria, structures' aesthetic assessment, Decision Support System, fuzzy logic, Intelligent Decision Support System with Fuzzy Logic.

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1. Introduction to Intelligent Decision Support Systems Using Fuzzy Logic

Identifying and characterizing a particular typology of DSS whose operation is based on data, information and input values with a high degree of uncertainty, incompleteness, subjectivity, difficulty in describing and quantifying them, consequently vague (fuzzy) led to the emergence of the Intelligent DSS that uses the fuzzy logic (IDSSF). This is the product of the DSS hybridization with the Expert System and the fuzzy logic operation mode.

The context which the fuzzy logic occurs with regards to the decision making process in is created by several premises [1]:
• the decisions take place in an ever-changing framework and with a continuous increase in complexity;
• the decision maker is constantly forced to keep up with the dynamics of the field in which he or she activates, a dynamic that is more and more difficult to control at normal human capacity;
• the success of the decision in an increasingly dynamic and demanding competitive environment requires increasing and complex forecasting skills;
• there are many subjective factors from the human component of a system, whose real importance is high, resulting in a realistic, non-algebraic, often unclear, imprecise framework;
• the solutions and the conclusions of the decision-making processes must prove flexibility and adaptability shortly after their generation in order to have a longer life time;
• these outputs often have to preserve the semantic abundance of the inputs, despite the inclusion of fuzzy reasonings, imprecise data and (near) random inherited information in inputs;
• the framework capable to manage these massive amounts of premises, having mainly unclear, imprecise, incomplete and dynamic qualities, can be supported by an expert system, hence the need to integrate some components of Expert Systems here.

The IDSSF components include, along those in the classical DSS structure, a base of quantitative models, that is needed to enrich the DSS with classification elements, templates, prediction tools and an inference engine taken from the Expert System. The quantitative model base is always found in a classic DSS. The inference engine is a homologue of the Rule System of the classic DSS, but here it is more specialized and operates with reasoning processes of induction, deduction, abduction and pseudo-arbitrary (the latter one for the particular IDSSP of our theme).

The operating way of a IDSSF is based on the multicriteria use of data containing linguistic variables and fuzzy values [2].

The methods for identifying the best answers to a problem or situation are divided into three categories [2]:
• methods for making rankings, by determining some values such as: comparison functions, fuzzy media, ideal proportions, optimization degrees, left-right distribution, centrification, area measurement, linguistic classifications;
• evaluation methods according to the importance of several attributes: fuzzy mass add-ons, analytical hierarchies, fuzzy hierarchies, fuzzy max-min method;
• fuzzy mathematical programming methods: flexible programming, probability programming, linear programming with fuzzy max, preferential fuzzy relationship programming, fuzzy programming object generation.

The implementation of the models is performed with the aggregation operators that are presented in the next section dedicated to fuzzy logic elements.

The framework and prerequisites of IDSSF have descriptions almost identical to the matter that we have dedicated this paper to, and that is why it was necessary to present them.

2. Fuzzy logic elements involved in an IDSSF

2.1 Introduction to fuzzy logic

By its nature, the aesthetic evaluation implies a high degree of relativism and imprecision because it operates with subjective, partially unknown, vague information, which is too difficult to manage with a system that operates with clear, crisp data.

The man uses easily the unclear, inaccurate or uncertain information, as in the statement: *This is more elegant than the other*. The imprecision is due to the impossibility of providing clear information. This is often the case within our theme. The decision-making system operating with vague, uncertain, partially unknown, fuzzy values is an Intelligent Decision Support System with Fuzzy Logic.

2.2 Fuzzy logic

The fuzzy logic was first described by the mathematician Lofti A. Zadeh in 1965 [3]. Yet, before Zadeh, Jan Lukasiewicz spoke of the polyvalent logic in [4] underlying the fuzzy logic. Strongly combated in the first years after publishing it, this logic was subsequently taken over and deepened by many specialists, among whom in the Romanian space are mentioned: Gelu Chisăliţă (TUCN), Mihaela Colhon (University of Craiova), Mihai Gavrilaș (“Gh. Asachi” Technical University of Iaşi), Mihai Ivanovici (Transylvania University of Brașov), Florin Lişman (TUCN), Gabriel Oltean (TUCN), Gabriela Proştean (Politehnica University of Timişoara) and others.

In essence, while the Boolean logic is based on the principle of the excluded third, in the binary system an element having either the value 1 or the value 0, in the fuzzy logic the elements have a lower or a higher degree of belonging to the interval between 0 and 1, i.e. $x \in [0,1]$. The fuzzy logic quantifies the uncertain, vague value of an element, as opposed to the Aristotelian logic of the excluded third.

In order to explain the fuzzy logic, a comparison of it with the Boolean (conventional) logic is further presented in this table:

Table 1: Comparison between the Boolean logic and the fuzzy logic

Boolean logic	Fuzzy logic
• it is characteristic to the human quantitative judgments, using numerical data	• it is characteristic to human qualitative judgments, using also lexical knowledge
• it performs classical logical operations	• it performs logical connections, predominantly logical operations with sets
• the knowledge is the process of the accumulation of variables	• the knowledge consists in finding the elastic fuzzy restrictions on a collection of variables
• by deduction, from clear premises through reasoning the conclusions are obtained	• by deduction the elastic restrictions propagate
• it operates with numeric variables	• it operates with linguistic variables
• it uses concrete data	• it uses partial, inaccurate data
• it can not manage contradictions	• it can manage contradictions
• both input and output values are algebraic	• both input and output values are fuzzy
• it is also called bivalent logic, using	• it uses linguistic variables that have

deterministic values: 1 = true and 0 = false	intermediate linguistic degrees, with the extremes 1 and 0
• it determines the presence, by associating the value 1, or the absence, by associating the value 0	• it determines the degree of belonging of an item to the linguistic variable using values from [0,1]
• it is based on the subset of the set of values {0,1}	• it is based on the subset which includes, besides the conventional values, also the ones from (0,1)
• it generates ordered pairs of elements, consisting of variables and the values {0,1}	• it generates ordered pairs of elements, made up of variables and the values [0,1]
• any situation is expressed with the values 0 and 1	• any situation is expressed with values from [0,1]
• the chosen function will reflect the presence or the absence of that element.	• the fuzzy function will reflect the membership of the element to the universe of scope set.

The visualization of the values association for elements in the classical logic, using binary values, respectively in the fuzzy logic, using value ranges, is graphically displayed in Figure 1.a and b:

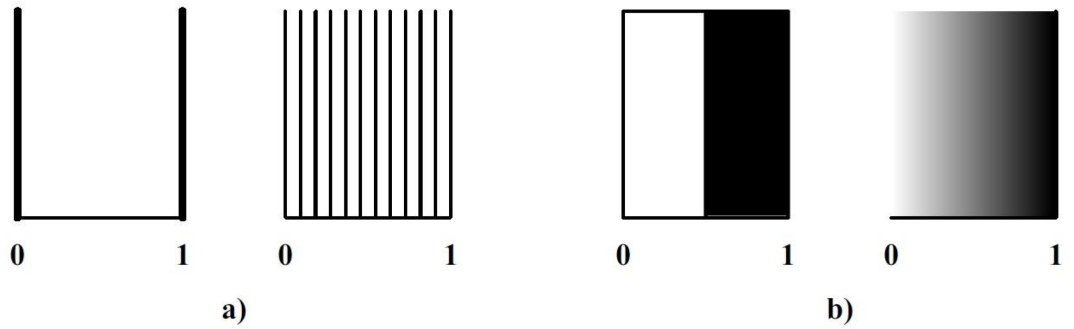


Figure 1. Visualization of the association of binary values and fuzzy values in two manners (a and b)

The membership of the element x to the interval [0,1] generates fuzzy sets that allow the computer to operate the human subjective interpretations, by attaching to them a meaning according to one or more predefined rules.

In the fuzzy logic, the items have uncertain values within an interval of values, and therefore they comprise the classical logic values at the upper and lower thresholds. Because of its specificity, the systems using fuzzy logic are dedicated to applications that operate with approximate, uncertain, incomplete, vague values, commonly referred to as fuzzy values.

The fuzzy logic captures more faithfully the logic used by man to make judgments, as the classical logic is a simplification of the fuzzy one, just in order to generate results faster and in a shape directly quantifiable.

2.3 Fuzzy sets

A fuzzy set consists of the pairs collection of linguistic variables which a value from the universe of scope has been attached to. The pair is called singleton. The edges of the fuzzy set are not clearly defined. The fuzzy set is defined as:

$$A = \{(x, f_A(x)) \mid x \in U\} \quad (1)$$

where: A – the fuzzy set

x – the variable's name
f – the membership function
U – the universe of scope associated with the membership function.

The generic universe of scope of the fuzzy sets is [0,1], being also called membership space.

The components of the fuzzy set are:
• the membership function: $f_A(x) : U \rightarrow [0,1]$
• the support of the fuzzy set consisting of elements with membership degrees not null:

$$\text{supp}(A) = \{ x \in A \mid f_A(x) > 0\} \quad (2)$$

• the height of the fuzzy set, being the highest value of the membership function:

$$h(A) = \max_{x \in T} f_A(x) \quad (3)$$

• the normality of the subset A, given by the existence of at least one unitary value of the membership function:

$$\exists\, x \in U \mid f_A(x) = 1 \Rightarrow A = \text{normal} \quad (4)$$

• can also be subjected to the classical sets' operations:
  ◦ reunion: $A \cup B$, $f_{A\cup B}(x) = \max(f_A(x), f_B(x)) = f_A(x) \vee f_B(x)$ (5)
  ◦ intersection: $A \cap B$, $f_{A\cap B}(x) = \min(f_A(x), f_B(x)) = f_A(x) \wedge f_B(x)$ (6)
  ◦ complementarity: C_A, $f_{CA}(x) = 1- f_A(x)$ (7)
  ◦ the algebraic product of the sets A and B, defined by the membership function:

$$f_{A\cdot B} = f_A \cdot f_B \quad (8)$$

  ◦ the algebraic sum of the sets A and B defined by the membership function:

$$f_{A+B} = f_A + f_B \quad (9)$$

The fuzzy set can also be defined as the result of the application of a function *f*, defined on a certain set U with results in the interval [0,1], to which the function of membership is characteristic, that is:

$$f_A(x) : U \rightarrow [0,1] \quad (10)$$

2.4 Membership to a fuzzy set

The degree or extent, which a linguistic variable is part of a fuzzy set to, represents the membership of that one to the set. The projection of the membership to the universe of scope is made by the function of membership, that is:

$$f_A : T \rightarrow [0,1] \quad (11)$$

The degree of membership varies continuously, as do the membership functions. Schematically, the membership of a linguistic variable to a fuzzy set is visually presented in Figure 2, inspired by the lecture of Mr. Mihai Gavrilaș [5]:

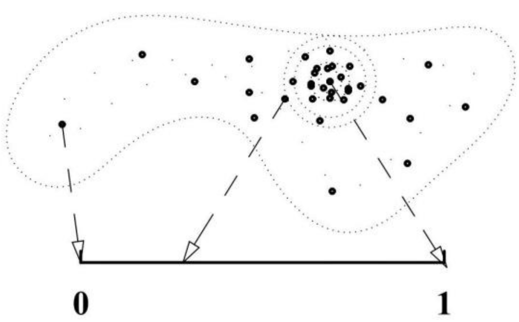


Figure 2. A visual representation of the membership of a linguistic variable to a fuzzy set

By membership functions, the variables of the universe of scope and the each one's degree of membership are connected. For example, the membership linguistic degrees low, medium and high can be attributed to membership functions that generate the graph in Figure 3:

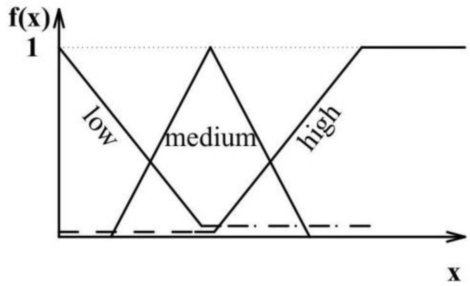


Figure 3. The graphic representation of the linguistic degrees with the respective functions

2.5 Membership function for a fuzzy set

The fuzzy sets are generated through membership functions of the variable to a fuzzy set. The membership functions are analytical expressions of the different degrees of membership of the analytical variable to the fuzzy set.

Mihaela Colhon describes in [6] six kinds of membership functions: triangular, trapezoidal, parabolic, harmonic, bell-type, saturation type (right ramp and, respectively, left ramp). Due to the already demonstrated fact that the choice of the membership function type does not significantly influence the final result, due to easier usage reasoning it is chosen the triangular membership function with which we will operate in the proposed by us application. This one is described by two first-degree equations that define, each one, a straight line that:

- crosses the point (a,0) and null (c,1), where x ∈ [a,c]
- crosses the point (c,1) and (b,0), where x ∈ [c,b]

That is:

$$f(x) = \begin{cases} \frac{x-a}{c-a}, a \leq x \leq c \\ 1 - \frac{x-c}{b-c}, c < x \leq b \end{cases} \quad (12)$$

And the graph of the triangular function is the one in Figure 4:

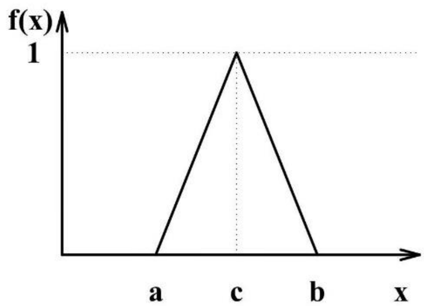


Figure 4. The graph of a triangular membership function

2.6 Fuzzy numbers

The fuzzy numbers consist of intervals of value also called confidence intervals, which the membership function is associated to, whose values are found in the range [0,1]. Obviously, these are not punctual values and differ from the algebraic numbers in the same way the fuzzy sets differ from the classical ones. Mihaela Colhon offers the following definition of the fuzzy numbers: *"A* *fuzzy number A is a fuzzy set of real numbers approximating another real number and having a membership function that is convex and continuous with a bounded support"* [6]. A fuzzy number is defined by its membership function, for example the triangular function, and similarly represented graphically – see Figure 4.

2.7 The linguistic variable

In fuzzy logic, the operating element is called a linguistic variable and it is a system composed of the following five elements [6],[7]:

• x = the variable's name

Ex.: *elegance*

• T(x) = the set of values associated with the membership function, consisting of primary terms that may have fuzzy linguistic modifiers such as: *very*, *almost*, *perhaps*, *little*, etc.

Ex.: *very low*, *low*, *medium*, *high*, *excellent*

• U = the universe of scope, the range of possible values

Ex.: *U = [0;10] (in value points or marks)*

• G = the grammar applied to syntactic rules in order to populate T(x)

Ex.: $$f_{high}=\begin{cases} 1, & for\ x \in [8,10] \\ \left(1+\frac{9-x}{5}\right)^2, & for\ x \in [0,8] \end{cases} \quad (13)$$

• M = the rule that triggers the attachment to each fuzzy set from U of a term from T(x)

Ex.: $M_{high} = \{(x, f_{high}(x)) \mid x \in [0,10]\}$ (14)

For the examples given in T (x) there are 5 rules, for example:

$$f_{excellent}(x) = \begin{cases} \frac{x-8}{2}, for\ x \in [8,10] \\ 1, for\ x = 10 \\ 0, otherwise \end{cases} \quad (15)$$

$$M_{e(excellent)} = \{(x, f_{excellent}(x)) \mid x \in [0,10]\} \quad (16)$$

2.8 The phases of the fuzzy modelling algorithm

The process of inferring the fuzzy variables runs through an algorithm whose steps are briefly presented below:

1. Establishing the heuristic values: creating a heuristic basis of the theme involves the use of the linguistic terms by one or more human experts in order to describe the problem to the uppermost extent. In the first step, raw information is introduced in the system, which will then be filtered out according to judgments or reasoning, to produce structured knowledge. This initial knowledge base is to be supplemented with fuzzy rules and specified adaptive functioning mechanisms.

2. The work variables: being fuzzy variables, they are divided into two categories: input variables and control variables (output variables). The input parameters may come from three possible sources: by direct measurements, by estimations through calculus, as a priori values. For a typical fuzzy model, the work variables can be continuous as informational signals or they may be discrete.

3. The universe of scope, the linguistic variables and the fuzzy sets: the universe of scope is the set of real numbers ℝ, more exactly continuous intervals from ℝ.

The linguistic values are fuzzy variables composed of words or expressions, of which the primary term and the fuzzy modifier are distinguished. These are to be associated with membership functions and thus form the set of linguistic values T(x). The fuzzy sets and membership functions have been outlined above.

4. The rules base for fuzzy inferences: the premises turn into conclusions through a logical operation called inference. The inference process is the event determined by the compositional rule that triggers the implication operator and the composing operator [6].

The most commonly used operators for implication are:
• Mamdani (the ~ implication), according the relationship:
$$m_{A\to B}(x,y) = \min[m_A(x),m_B(y)] \text{ – the min operator} \quad (17)$$
• Larsen (the ~ implication), according the relationship:
$$m_{A\to B}(x,y) = m_A(x) \times m_B(y) \text{ – the product operator} \quad (18)$$
And the most commonly used composing operators are:
• Mamdani (the ~ composing), according the relationship:
$$f_R(x,y) = \max\{\min(f_A(x,y), f_B(y,z)) \mid z \in C\} \text{ – the max-min composing} \quad (19)$$
• Larsen (the ~ composing), according the relationship:
$$f_R(x,y) = \max\{f_A(x,y) \times f_B(y,z)) \mid z \in C\} \text{ – the max-product composing} \quad (20)$$

The existence of a premise generating conclusions in the form of logical consequences gives rise to a rule. The rule is the product through which the prerequisites (P_i, $i = \overline{1,n}$) are composed (∟) with pre-established logical operators in order to generate the consequence (C), according the relationship:
$$P_1 ∟ P_2 ∟ \ldots P_n = C \quad (21)$$

Generally, a fuzzy system is a sum of defined functions in the form:
$$S : P^n \to C^m \quad (22)$$
where: S – the fuzzy system
P^n – all *n* fuzzy subsets that contain the input variables
C^m – all *m* fuzzy subsets that contain the output variables

The fuzzy system S is referred to as the Fuzzy Rules Base, which is predetermined by the human linguistic experts and introduced into the application which they are dedicated to. For this reason, in the aesthetic evaluation, it was sought the system solution that operates with linguistic expressions and is capable of delivering crisp output.

5. Fuzzing, inferring and defuzzing: the fuzzy logic is dedicated to processing vague (uncertain) knowledge through logical reasoning, using a number of membership functions and the Fuzzy Rules Base. Typically, the input values are crisp (opposed to fuzzy and thus algebraic values), and therefore the architecture of a fuzzy controller [8] follows the scheme in Figure 5:

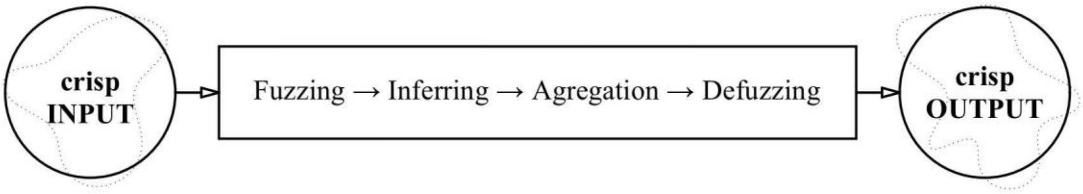


Figure 5. The architecture of the fuzzy controller

The fuzzing process is carried out after the definition of the fuzzy numbers, as described above. The logical inferring process is performed according to the Fuzzy Rules Base, defined at the previous stage of the modelling algorithm.
The defuzzing is the process by which the fuzzy system converts the result obtained as a fuzzy set into a crisp value [6]. Of the defuzzing methods, the most commonly used are: the center of gravity method and the maximum average method. By the center of gravity method (CG), the variable belonging to the output fuzzy set and is found at the center of gravity of the membership function

values is converted to a crisp value according the formula:

$$y_{CG} = \frac{\int x f(x) dx}{\int f(x) dx} \qquad (23)$$

By the maximum average method, a variable with maximum membership in the output fuzzy set is chosen and is defuzzed in three possible ways: the maximum average, the lowest maxima and the highest maxima [9].

6. Adaptation, learning and the software: the last step of the algorithm describes the system's adaptation mechanisms and the autonomous learning schemes, for the software to achieve its purpose in the most effective manner.

The adaptation mechanisms and the learning schemes applicable to our proposal have already been described in the first part of the paper, in the section dedicated to the *Particular Decision Support System*. Its application is described in the next section.

3. Proposal of an application for the structures' aesthetic evaluation

3.1 Modern ways of evaluating structures

The characteristics of the structures' aesthetics and the context of its assessment are the premises of a customized typology of decision-making process. The aesthetics of the structure is an area in continuous process of definition, as we previously mentioned in our PhD thesis, because it is defined in the same time with the definition process that human society performs, while going through a certain period of time. At the moment, a commented and enriched compilation of the visions of reference engineers from global and national (regional) level has been made, in order to generate a momentary radiography of the definition of structures' aesthetics.

Given the observations made by specialists and non-specialist people about some insufficiently exploited or valued aspects at national and regional level, it was expected to seek for an answer to the challenge of the development strategy in the aesthetics of structures. For this reason, a list of categories of aesthetic criteria was presented in the First Part of this paper, as a support for the evaluation of the structures both in the design phase and after its realization. The discussion takes place in terms of massive impact objectives, either public objectives or private objectives that have a major impact on the environment built around their location. This impact can be shaped up with the support of specialists and people in the public who want to get involved in this process. The final beneficiary of the effects of a construction is, in fact, the citizen, i.e. the public.

Regarding the mention we made in the First Part of this paper, referring to our view that man can never be replaced plenary by a computer (robot), we add here that an important component of the public's satisfaction in exploiting an objective is due to its involvement, in a manner at least consultative, in the decision-making process for that structure.

This section of the paper proposes a decision-making micro-system on the aesthetic evaluation of the structures, involving a knowledge base which the programmer-specialist operates with and a database collected from the public. Collecting the public opinion within the evaluation of some structures is proposed in a modern way, in the shape of an on-line questionnaire based on categories and criteria, which makes multiple invitations to propose other relevant categories and criteria that will contribute to a more comprehensive assessment. Centralizing the results of the public is followed by processing and inferring the fingerprint of each structure using a unique, dedicated software that uses specific fuzzy logic elements. The knowledge base of this IDSSF includes: fuzzy input sets, a Fuzzy Rules Base and fuzzy output sets that are reflected in the application's content through the phases of the fuzzy modelling algorithm. The fuzzy logic brings a great advantage in this regard, giving its user the freedom to participate in the elaboration of the fuzzy membership functions. Another reason why the fuzzy model was chosen for our theme is because within this model, from the beginning, the partial, imprecise, vague dependence between the input variables and the output variables is taken into account, based on non-deterministic and non-linear interactions [6].

The particularities of the fuzzy modelling algorithm dedicated to the application that we designed to support the aesthetic evaluation of the structures are presented below:
• the linguistic variables consist of aesthetic evaluation criteria;
• the entry variables are made available to respondents through the on-line questionnaire, where they can intervene to select the criteria they consider relevant and to propose other, different, important ones in reflecting the aesthetic value of the structure;
• the variable may be continuous and discreet at the same time for different respondents in the assessment of the same objective due to his or her freedom both in selecting those criteria that he or she considers relevant and in proposing and including in evaluation criteria other than those made available;
• the grammar applied to the syntactic rules for generating the set of values associated with membership functions is a component of the application and was established during its construction.

The two components of the proposed solution, the on-line questionnaire and the application, are presented in the sections below.

3.2 Collecting the raw data

The data collecting process takes place through the on-line questionnaire. The respondents are people non-specialist in the field, anonymous from the audience, whom we have invited to make an assessment using a few guiding lines that offer freedom of expression and opinions.

The structure and the explanations of the questionnaire generated through the Google Docs support [10] are presented below:
1. Introduction with the presentation of the purpose of the questionnaire, having in the title the project to be evaluated – see Figure 6.

Figure 6. The first section of the on-line questionnaire with its presentation

2. The description of the objective to be assessed, accompanied by representative images – see Figure 7.

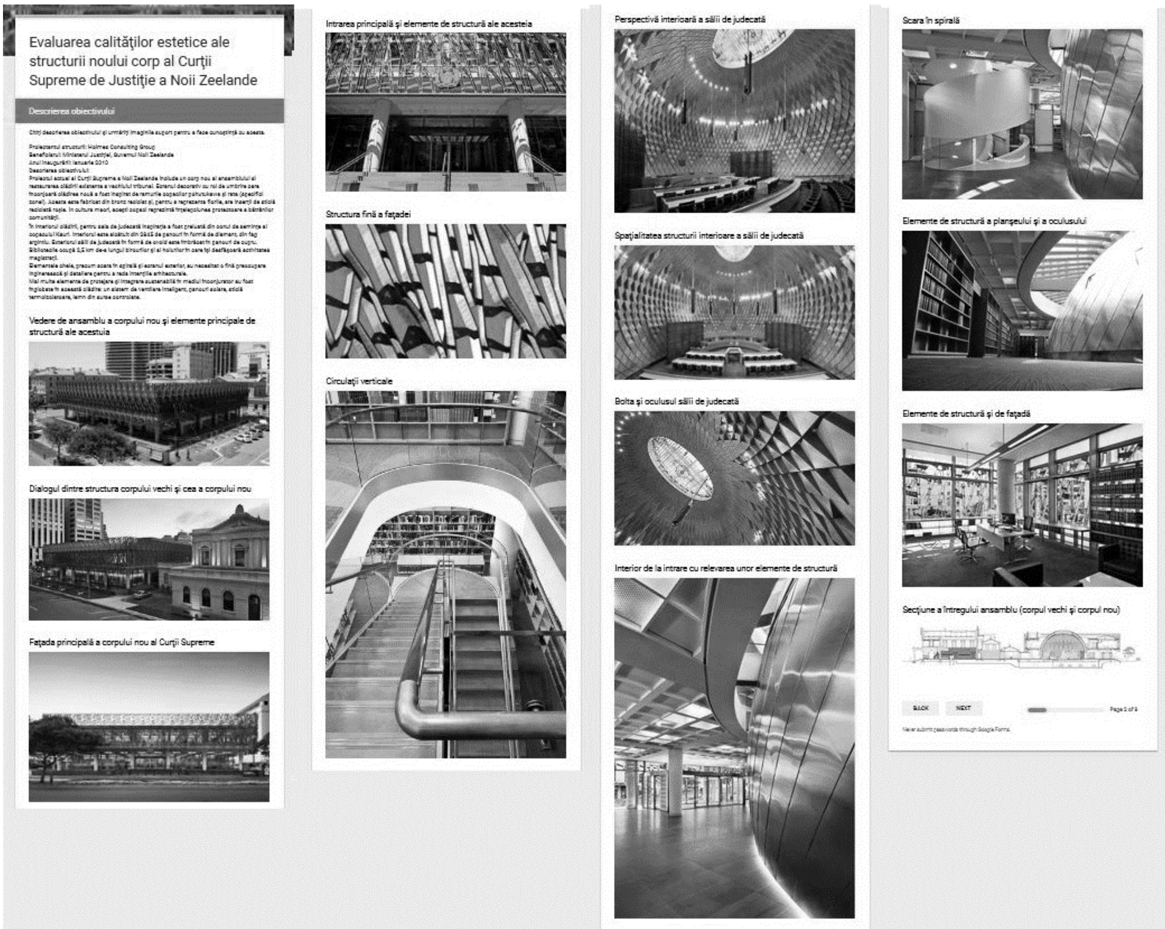


Figure 7. The second section of the on-line questionnaire presenting the objective in assessment

3. The selection of the criteria categories which the respondents consider the assessment to be relevant within, giving the freedom to introduce other categories of criteria beside the ones proposed, followed by the specification of the importance percentage of the selected and / or specified categories – see Figure 8.

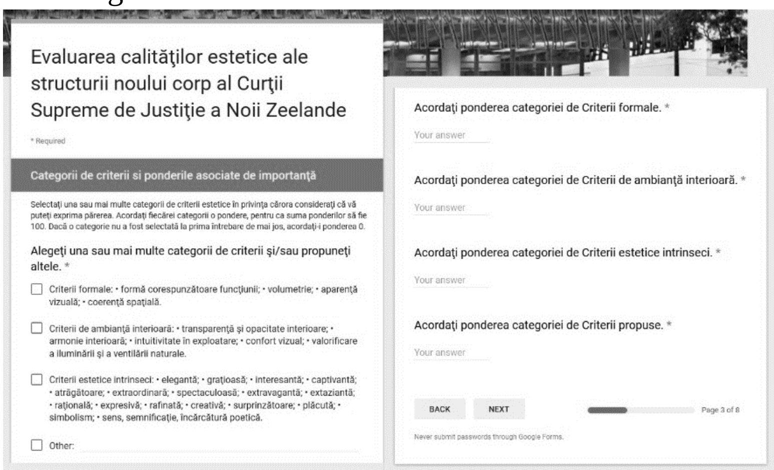


Figure 8. The third section of the on-line questionnaire setting out the criteria categories

4. Selecting relevant criteria, proposing others not available, and marking each of them. This process takes place for each category of criteria selected and / or specified in the previous paragraph – see the example referring to the first category of criteria selected in Figure 9.

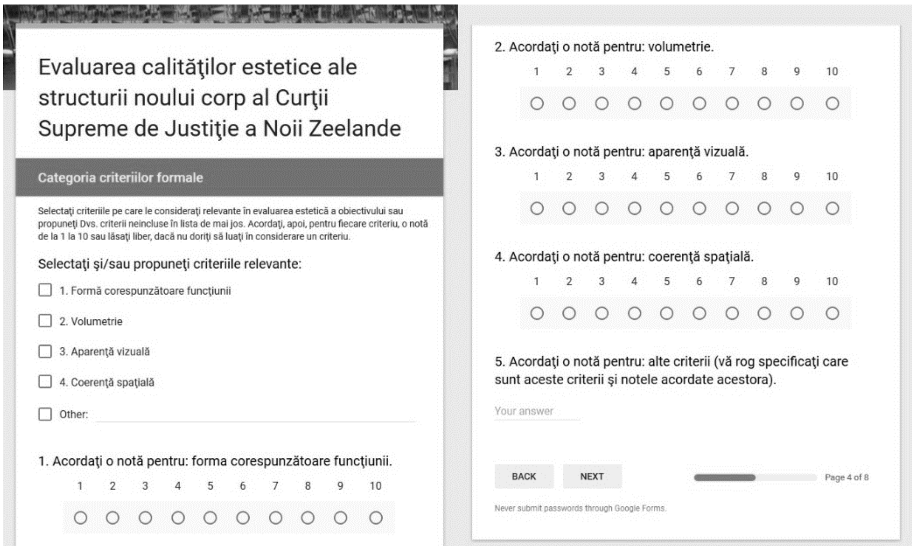


Figure 9. The fourth section concerning the first category of criteria considered

5. The previous step is repeated for each category of selected and / or proposed criteria. If a single category of criteria has been selected, this is the before last step.

6. Sending the results and closing the questionnaire – see Figure 10:

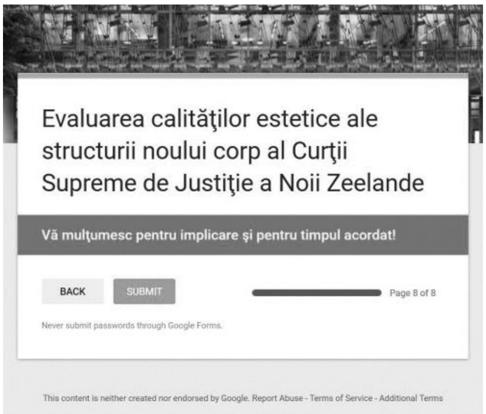


Figure 10. The last section closes the questionnaire and sends the answers

The results obtained from the completion of the questionnaire are collected and processed through the application created in the JAVA IntelliJ IDEA development environment, that is presented below.

3.3 Processing the data

The general programming language JAVA provides support for the FuzzyLite library [11] that was used to build a fuzzy system for aesthetic evaluation of structures using the jfuzzylite 6.0 library. The language operates here with fuzzy algorithms, as described in section 4.3. Elements of fuzzy logic involved in a IDSSF.

The application, built up with the help of the programmers Ciprian and Teofana Mateș, required the import of the libraries typical for the fuzzy algorithms and the selection of the fuzzy values operating modes, being dedicated to a category of evaluation criteria. The evaluation criteria have been specified and defined as fuzzy linguistic inputs. The output was also defined as fuzzy variables. The inferences used are Mamdani and Takagi-Sugeno, while the rules of inference are specified.

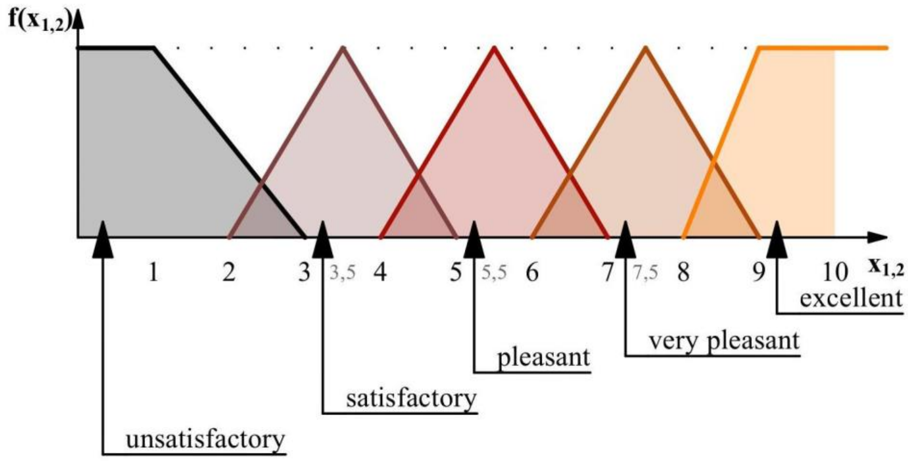
The application has two use modes. The first one, the advisory mode, systematically displays the rules generated for the inference process as input values, providing all the outputs for all the input value possibilities. The second one is the operative mode, which allows the introduction of crisp values for each criterion, in order to finally generate the crisp result after applying the appropriate inference rule. This crisp result is the digital fingerprint for the respective category of criteria, of the evaluated structure, using the values provided by the respondents to the questionnaire.

The linguistic variables were described as follows:

```
#File: ObstacleAvoidance.fll ArchitectureAesthetics.fll
Engine: ObstacleAvoidance
InputVariable: obstacle
  enabled: true
  range: 0.000 1.000
  lock-range: false
  term: left Ramp 1.000 0.000
  term: right Ramp 0.000 1.000
OutputVariable: mSteer
  enabled: true
  range: 0.000 1.000
  lock-range: false
  aggregation: Maximum
  defuzzifier: Centroid 100
  default: nan
  lock-previous: false
  term: left Ramp 1.000 0.000
  term: right Ramp 0.000 1.000
RuleBlock: mamdani
  enabled: true
  conjunction: none
  disjunction: none
  implication: AlgebraicProduct
  activation: General
  rule: if obstacle is left then mSteer is right
  rule: if obstacle is right then mSteer is left
```

For example, for the formal criteria category, the graphs of the linguistic variables and the associated value sets (T (x)) are shown below – see Figures 11, 12 and 13:

U = [0,10]
x_1 = volumetry
$T(x_1)$ = {unsatisfactory, satisfactory, pleasant, very pleasant, excellent}
x_2 = function correspondence
$T(x_2)$ = {unsatisfactory, satisfactory, pleasant, very pleasant, excellent }
x_3 = spatial coherence
$T(x_3)$ = {low, average, high}
x_4 = visual appearance
$T(x_4)$ = {low, average, high}
r = formal aesthetic quality



T(r) = {low, intermediate, high}

Figure.11. The graph of the variables *volumetry* and *form correspondence* with their associated values

Programming the descriptions for the linguistic variables *volumetry* (volumetry) and *form correspondence to function* (function_correspondence), see Figure 11, it looks like this:

```
description: (volumetry and function_correspondence and
spatial_coherence and visual_appearance) ->
(formal_aesthetic_quality)
InputVariable: volumetry
  description: volumetry
  enabled: true
  range: 0.000 10.000
  lock-range: true
  term: unsatisfactory Trapezoid 0.000 0.000 1.000 3.000
  term: satisfactory Triangle 2.000 3.500 5.000
  term: pleasant Triangle 4.000 5.500 7.000
  term: very_pleasant Triangle 6.000 7.500 9.000
  term: excellent Trapezoid 8.000 9.000 10.000 10.000
```

Practically, for the qualifying *very pleasant* the linguistic value has a triangular shape and is described by three points specified in the order of their projections on the abscissa: 6.000 7.500 9.000, while for the qualifying *excellent* the value is a trapezoidal one, described by four points: 8.000 9.000 10.000 10.000. For the linguistic variables *spatial coherence* (spatial_coherence) and *visual appearance* (visual_appearance), see Figure 12, the description is as follows:

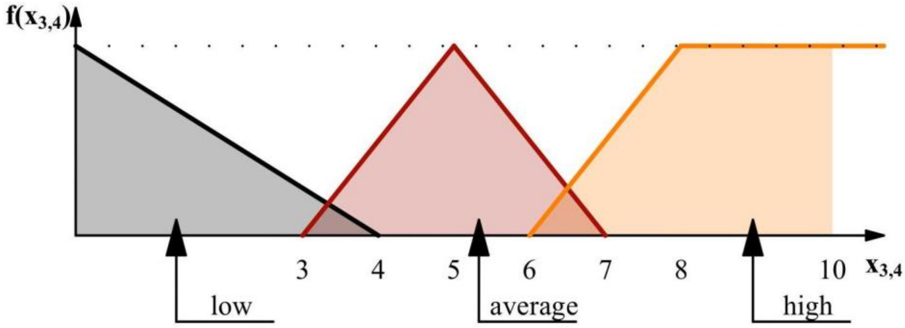


Figure 12. The graph of the linguistic variables *spatial coherence* and *visual appearance* with their associated values

```
InputVariable: spatial_coherence
  description: spatial_coherence
  enabled: true
  range: 0.000 10.000
  lock-range: true
  term: low Ramp 0.000 4.000
  term: average Triangle 3.000 5.000 7.000
  term: high Trapezoid 6.000 8.000 10.000 10.000
```

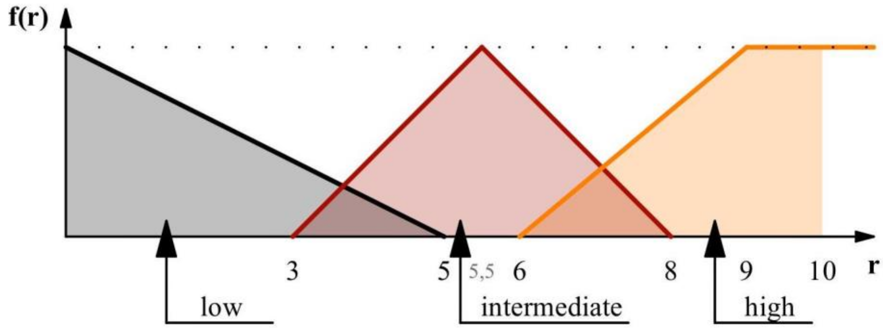


Figure 13. The graph of the linguistic variable *formal aesthetic quality* with its associated values

The output, according to the graph in Figure 13, has been described as follows:

```
OutputVariable: m_formal_aesthetic_quality
  description: formal_aesthetic_quality based on Mamdani inference
  enabled: true
  range: 0.000 10.000
  lock-range: false
  aggregation: Maximum
  defuzzifier: Centroid 100
  default: nan
  lock-previous: false
  term: low Ramp 0.000 5.000
  term: intermediate Triangle 3.000 5.500 8.000
  term: high Trapezoid 6.000 9.000 10.000 10.000
OutputVariable: ts_formal_aesthetic_quality
  description: formal_aesthetic_quality based on Takagi-Sugeno
inference
  enabled: true
  range: 0.000 10.000
  lock-range: false
  aggregation: none
  defuzzifier: WeightedAverage TakagiSugeno
  default: nan
  lock-previous: false
  term: low Constant 3.000
  term: intermediate Constant 6.000
  term: high Constant 9.000
```

The results of the inference process for determining the *formal aesthetic quality* are described by three triangular values partially overlapped and associated with the qualifyings *low*, *intermediate*, *high*. The reason for overlapping the values is given by the fact that the implication of multiple criteria in the evaluation raises the fuzziness level of a result obtained by conjugating some initial fuzzy data. For example, a 6.8 output denotes both a high quality of the formal aesthetics and an intermediate quality of it. The membership of a crisp result to two different linguistic intervals is typical for the human evaluations of the subjective qualities of objects, making this system a true and fair solution of assessment. The solution is a hybrid one, both the man and the computer contribute to determine the aesthetic qualities of the structures.

For the Mamdani inference, the prod-max aggregation method and the defuzzing by CG have been set. For the Takagi-Sugeno inference, the defuzzing was defined as the maximum (MOM) [9], of 0 (constant), with steps 3, 6 and 9.

The upper threshold has been set constantly at 9.000, but this does not mean that the aesthetic evaluation made with this proposal never recognizes the full merit associated with *mark* 10 to any structure. This is more a generic value chosen in order to denote the permanent opportunity to create goals for a higher aesthetic quality than the one already existing, and it owns a more psychological and symbolic value.

Some inference rules are shown below:

```
if volumetry is excellent and function_correspondence is excellent
and spatial_coherence is average and visual_appearance is high
then m_formal_aesthetic_quality is high with 0.8

if volumetry is excellent and function_correspondence is
very_pleasant and spatial_coherence is high and visual_appearance
is average then m_formal_aesthetic_quality is high with 0.8

if volumetry is very_pleasant and function_correspondence is
excellent and spatial_coherence is high and visual_appearance is
high then m_formal_aesthetic_quality is high with 0.8

if volumetry is very_pleasant and function_correspondence is
very_pleasant and spatial_coherence is average and
visual_appearance is average then m_formal_aesthetic_quality is
high with 0.4

if volumetry is very_pleasant and function_correspondence is
pleasant and spatial_coherence is high and visual_appearance is
high then m_formal_aesthetic_quality is high with 0.4

if volumetry is pleasant and function_correspondence is excellent
and spatial_coherence is average and visual_appearance is high
then m_formal_aesthetic_quality is high with 0.4

if volumetry is pleasant and function_correspondence is
very_pleasant and spatial_coherence is high and visual_appearance
is average then m_formal_aesthetic_quality is high with 0.2
```

The values set associated with the result, the *formal aesthetic quality*, is T(r), the final result offered in crisp shape.

4. Conclusions

The assessment of the structures' aesthetics is a complex process, both in essence, for the identification, selection, ranking and quantification of the criteria, and in shape, relative to the manner in which the process can take place. The tools with which this can be done in a consistent and relevant way must be highly specialized, designed for this particular purpose.

In addition to the many advantages that the contemporary scientific and technological progress makes available for designing and building constructions with high aesthetic value, this progress also supports the assessment process too. While the publishing, the acceptance, and further the sedimentation of the fuzzy logic has taken place over the last half century, the consolidation of the theoretical basis for intelligent decision-making systems has occurred only over the past three decades. The main intelligence input in the IDSSF is due to developments in the field of the Artificial Intelligence, that has triggered the evolutionary phases of the practical integration of these resources into other areas.

A real satisfaction is generated by furthering of current resources in achieving the purpose of this paper: the aesthetic evaluation profile is embedded in the fuzzy logic operation mode. Continuing the implementation of the provided solution, that works on the basis of fuzzy logic, managing to provide reliable data to the user (the evaluator responsible for the process), directly contributes to the aim's achievement.

The assumption we initially made, that only a complex and vast system can consistently handle this theme, has been confirmed by the followed researches, but here is recalled the mention that IDSSF helps the decision maker in the evaluation process, remaining anthropocentric. The furthering of the theoretical resources regarding DSS, fuzzy logic and IDDSF is already a gain, the more is their application supported by a complementary application.

The use of the application proposed here is continued in a separate paper called *The application of a software using fuzzy logic in the evaluation of the structures' aesthetics*, which is subject to a series of internationally-awarded objectives, including an unofficially labeled *ugly* objective. It is interesting to observe that the award given by an expert commission of a high international recognition for a structure is also confirmed or not by the respondents' opinions, just as it will be interesting to observe how ugly is considered by the public a structure labeled in the on-line environment as such. Of course, the ways in which the evaluations are carried out by the two categories, the specialists and the public, do vary considerably, as well as the amount and form of the information they have at their disposal. However, when a DSS is used, it is predisposed to generate the disadvantage of being able to overwhelm the decision-maker through the amount of information. The public is even more sensitive to this, so the presentation of the information for it must be adapted in order to attract its interest and desire for sincere involvement. The public is more spontaneous and hence more sincere, but it is also superficial and harder to engage. The integrated success of our proposal will also be reflected in the consistency of the responses from respondents.

In the same time with the society's evolution, the ways and tools for assessments must continue to develop and adapt to both the profile of the specialists and the personality of the public in order to keep their characteristic of being interesting and the participation to the process to bring satisfaction to the questioned people.

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