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# A Proposed Framework for Automated Evaluation of Architectural Spatial Configurations Using Fuzzy Logic Approach

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Fuzzy logic, Space layout planning, automated evaluation.

## Abstract

Architectural spatial layout configurations are the result of a complex design process aiming at managing the most advantageous location of all spaces with certain objectives and constraints. In the presence of broadening the scope of understanding spatial configuration, its role, and its composition in scope of various programmatic, ideological, formal, and engineering aspects, embedded in a complex theoretical background. The aspect of evaluation was the least apparent and there were significant limitations to what can be achieved there. This paper is aiming at evaluating functionality (such as quality of space, use, Access, adjacency, non-adjacency, proximity etc.), build quality (such as performance, efficiency, cost, etc.), impact (such as user performance, internal quality, urban, social, and cultural integration, etc.), indication of the quality of the architectural space design and the quality of the layout configuration. To achieve this research goal, we devised all possible spatial relation, affecting these qualities, as inputs for a given architectural space using descriptive rule blocks. We defined this fuzzy logic system for residential spaces that has been blended into a layout to evaluate the layout configuration. We defined all input variables, output variables, and fuzzy sets, and present space-space relations using membership functions. The paper proposes a framework based on fuzzy logic approach for automated evaluation of architectural spatial layout configurations.

## 1. Introduction

Historically, intuitive design has been dominating as the most frequent form of architectural practice. However intuitive mechanisms are insufficient when it comes to managerial abilities combination such as technical, technological, aesthetical, social, and economical aspects. Every design process in architecture is a reflection of social life and, at the same time, an attempt to process various types of data as well as transforming physical components to

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improve human-centered environment. It is necessary to define the aim of this paper being a prolegomenon for understanding that evaluation of The Output Quality of design process as a decision-making process of a complex nature that is relative rather than being absolute. Therefore, determining the quality of the output is complex in presence of several critical aspects of The Evaluation Criteria. Nonetheless, several tools have been developed with different approaches to evaluation to address the issue of evaluation, Design Quality Indicator (DQI) [7], AEDET Evolution (Achieving Excellence Design Evaluation Toolkit) [8], Design Excellence Evaluation Process (DEEP) [9], Housing Quality Indicator (HQI) [10],[11], Leadership in Energy & Environmental Design (LEED) [12], Building Research Establishment Environmental Assessment Method (BREEAM) [13], and Building Quality Assessment (BQA), All of them have a great reputation in scholarly publications and their actual frequency of use according to literature reviews as shown in table 1 [2], a study of the strengths and weakness in addition to a summary of Design assessment tools have been concluded in table 2. The success of the design while achieving the standards in any of these evaluation tools doesn't guarantee that it will pass the standards of the other evaluations at the same level. Thus, it can be concluded that the optimum design is a convergence in between all the standards of these tool. Consequently, there has always been a need for the presence of a percentage-based evaluation tool rather than the binary logic evaluation such as Fuzzy Logic Curve.

Fuzzy logic approaches are based, as opposed to classical two-valued logic that assumes only true or false propositions, on propositions that may be both partially true and partially false. The classical set demonstrates one and only true value for a finite number of logical variables. In fuzzy logic, however, input variables are passed into the fuzzy logic system as a fuzzy variable, presented as a vector of membership degrees, as they stem originally from a qualitative or linguistic source. Fuzzy logic systems have recently been proposed to address ambiguity in architectural design approaches and requirements, specifically, in managing uncertainty and soft qualities in spatial layout design. This paper presents Fuzzy logic curve as an approach to the automated evaluation of spatial layout configurations, by conducting the different spatial parameters of the space and identifying the spatial relations between these spaces, involving analyzing spatial characteristics and space-space relations to assess soft qualities such as quality of space, use, Access, adjacency, non-adjacency, proximity, performance, efficiency, cost, etc.

**Table 1: Design quality assessment tools review.**

| | DQI | AEDET | DEEP | HQI | LEED | BREEAM | BQA |
|---|---|---|---|---|---|---|---|
| 1)Building Type | Educational Buildings in Specific. (Can also be used on wide | Hospitals (Health Care facilities) | Military Housing | Housing (schemes) | All types of buildings (residential to commercial) | Housing Eco-homes Office Schools Industrial build. Courts Healthcare Prison Retail | Office buildings |

| | DQI | AEDET | DEEP | HQI | LEED | BREEAM | BQA |
|---|---|---|---|---|---|---|---|
| | variety of buildings) | | | | | education (Other types of buildings) | |
| | DQI, LEED and BREEAM can be used for a wide variety of buildings, while the rest is related with a specific building type. | | | | | | |
| 2)Aim of Use | - Architectural design quality (ADQ) assessment | -ADQ Assessment - Benchmarking | -ADQ Assessment -Generic Checklist | - Measurement and assessment of potential and existing house schemes based ADQ | -Green building certification system | -Sets the standard for best practice for sustainability | - Performance assessment |
| | DQI, AEDET, DEEP and HQI aim to assess architectural design quality. LEED and BREEAM try to set the standards for certification of green buildings, while BQA aims to assess the performance of office buildings. | | | | | | |
| 3)Main Criteria SubCriteria | - Functionality Use Access Space - Build Quality Performance Engineering sys. Construction -Impact Character &Innovation Urban & social Integration Staff Environment | - Functionality Use Access Space - Build Quality Performance Engineering sys Construction -Impact Character &Innovation Urban &social Integration Staff& Patient Environment | - Functionality Client Operation Single Living Accommodation Innovation - Build Quality Performance Engineering sys Building Fabric Innovation - Impact Context & estate Planning Form & appearance Internal Environment Conversation of buildings | -Location -Site Visual Impact Open space Routes &movement -Unit Size Layout Noise, light, services, and adaptability Accessibility Sustainability - External environment Size | - Sustainable Sites -Water Efficiency - Energy and Atmosphere - Materials and Resources - Indoor Environmental Quality - Location& linkages - Awareness &education - Innovation in | - Management Life cycle cost Site investigation -Health and well Being Lighting Water Noise control - Energy Co2 emissions Energy Use Noise control - Transport Public Transport Cyclist Deliveries - Water Recycling Irrigation sys. - Materials Re-use Insulation - Land use &Ecology | - Presentation -Space functionality -Access and circulation -Business services - Amenities -Working and environment -Health and safety -Structural considerations - manageability |

| | DQI | AEDET | DEEP | HQI | LEED | BREEAM | BQA |
|---|---|---|---|---|---|---|---|
| | | | Sustainabilit y | | design - Regiona l Priority. | Re-use Ecological value Biodiversity -Pollution Water sources Refrigerant leaks - Innovation | |
| | The tools use adapted Vitruvian frameworks which can be defined as functionality, build quality and impact, extended with ecological approaches like sustainability, health, wellbeing and preserving resources for assessment of architectural design quality. For assessment, design quality is seen as a degree of excellence within the intersection of the main criteria with their sub-criteria. | | | | | | |
| 4)Adaptabi lity /Flexibility | General adaptation | General adaptation | General adaptation | General adaptation | General adaptati on | Adaptability for each building type | No adaptabilit y |
| | No flexibility to change or adapt the criteria for different tasks. General modifications or updates on the system take time to get in action in further versions, which makes it hard to adapt the tools case based specific | | | | | | |
| 5)Methodol ogy | Structured workshop, online form, and questionna ires | Stand-alone forms, Workshop s | Stand Alone Forms Workshops (in some cases) | Stand-alone forms | Online certifica tion | Stand-alone forms | Software based survey |
| | The tools make assessment via standalone forms or in some cases with web based online surveys/questionnaires to reflect stakeholders' priorities. DQI, AEDET and DEEP also use workshops to get individual priorities. LEED, BREEAM, BQA use threshold levels for assessment of quality. | | | | | | |
| 6)Scope of Assessment | Achieve the best building possible based quality. | Evaluate the quality of design in healthcare buildings. | Identify and minimize risk in the design of projects (MOD Building) | Measure ment and assessmen t of potential and existing house schemes-based quality | Acceler ate the adoptio n of green building practice s | Energy and sustainabilit y | Assessme nt of Performan ce of a building |
| | DQI, DEEP, AEDET, HQI assess the design quality. LEED and BREAM certificates buildings related to energy usage and sustainability, while BQA assesses performance of a building | | | | | | |
| 7)Phase of Building Process | All stages of building | All stages of building process | All stages of building process | Design and in use | All stages of | Design and in use | Post occupancy evaluation |

| | DQI | AEDET | DEEP | HQI | LEED | BREEAM | BQA |
|---|---|---|---|---|---|---|---|
| | process including all design stages. | including all design stages. | including all design stages. | | building process including all design stages. | | (can be carried out to design stages) |
| | All tools claim that they can be used within all stages of building process from briefing to in use. Although the tools are introduced as they can be used in any stages of the building process, they can be used effectively in post occupancy evaluation (POE). | | | | | | |
| 8)Organization (stakeholders) | Internal and external stakeholders (Especially users) | Internal and external stakeholders | Internal and external stakeholders | Internal and external stakeholders | Commercial building project stakeholders or project team members | Internal and external stakeholders | Internal and external stakeholders |
| | The intention behind the tools on design quality is to get ideas for the stakeholders, especially from users, for the assessment of architectural design quality. Getting stakeholders ideas is a big plus to achieve success for integrated design teams, however transferring ideas to design process as knowledge for design teams can be underlined as missing part of the tools. Tools generally aim to score a building in general, rather than transferring knowledge to design teams. | | | | | | |
| 9)Weighting System | Likert/Rating Scale | Likert/Rating Scale | Likert/Rating Scale | Likert/Rating Scale, Yes/No Questions | Likert/Rating Scale | Likert/Rating Scale | Likert/Rating Scale |
| | All the tools use adapted Likert/rating scale system for assessment. Some of them are using verbal scales while others use point scaling system. HQI also asks Yes/No questions. | | | | | | |

## Table 2: Design quality assessment tools review.

| Strengths | Weaknesses |
|---|---|
| • Tools tend to be used for assessment of design quality in a wide variety of buildings, although there are still limitations. • Criteria selection mostly are based on a Vitruvian like framework and sustainable principles often after extended discussions and many iterations before these terms were agreed upon. (Gann et al., 2003) • Dewulf and van Meel (2004) stress that the recognized importance of the built environment makes it necessary to discuss design quality with laymen, architects, government, and other stakeholders. As evidence, there is a growing intention of the tools to get stakeholders ideas, | • Although the tools can be used for different types of buildings and for different phases of building processes, it is still a problem to adapt the underlying system of the pre-defined sets of criteria (something all above mentioned tools have in common) for making a case base specific design evaluation. • The tools have problems to contribute to design stages since they are not succeeded to make comparative assessment of design alternatives. • Most often the tools must be used with expert facilitators, or are at least assumed to, which make assessment process tough considering total numbers of |

| Strengths | Weaknesses |
|---|---|
| especially users, for assessment of architectural design quality. Reflecting stakeholders' priorities in building processes is a big plus to achieve success for integrated design teams. | stakeholders and time needed. • A big concern for all the tools reviewed is their weighting systems and their methodologies which they use for assessment. All the tools reviewed use a Likert/rating scale system, some of which use verbal judgments while the others use point system for scaling (HQI also uses Yes/No questions). Outcomes of the surveys related to assessment contain heterogeneous data since using this methodology it is not clearly known what the relative importance is of each criterion and sub-criteria to each other. • Another problem is the lack of consistency measurement. Consistency cannot be checked until a certain number of participants exist. As the tools intend to get also non-expert stakeholders' ideas, consistency should be considered, and inconsistent surveys should be avoided. |

## 2. Space Layout Planning & Fuzzy Logic

To indicate the quality of space configuration during design phase of any project, many factors should be considered to evaluate the output of the design process to reach optimum design. Architects deal with many factors of space layout planning such as dimensional factors of each space including length, width, space orientation, and topological factors among different spaces such as adjacency and proximity as well [3]. Currently, architects solve these problems manually by sketches that represent space planning principles, then they refine these sketches to reach suitable space areas and proportions. While they are trying to deal with those constrains, a "strong" or "weak" relationship between two spaces might be defined in the conventional spatial relation matrix diagrams based. These relationships are typically defined generically and may discard a wide spectrum of parameters and variables which could affect other spatial relations, resulting in partially appropriate solutions for spatial configurations[4].

Space layout planning (SLP) is considered a difficult area of computer aided architectural design (CAAD), as the topological assignment and the dimensioning of space elements need to meet certain criteria and constraints. Critical difficulties include the complexity of design information and spaces relations, and the layering of multi-criteria optimization as well. Thus, applying suitable computational model may enhance structuring SLP via multi criteria decision making (MCDM) process[5]. In this respect, fuzzy systems could be appropriate to objectify such complicated and subjective decision-making process. Fuzzy logic and set theory were coined by Lotfi A. Zadeh in 1965 as an alternative for binary logic[6]. This approach allows partial belonging; values in the interval [1 - 0] from the highest level of compatibility (1) to non-compatibility (0). Fuzzy logic approaches are based, as opposed to classical two-valued logic that assumes only true or false propositions, on propositions that may be both partially true and partially false as shown in fig. 1 [1].

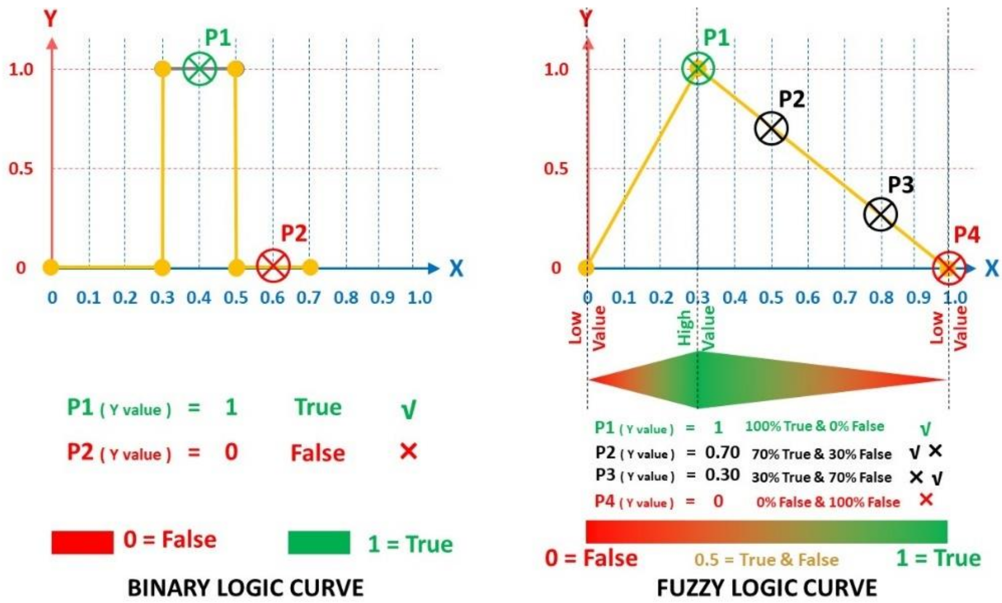


Fig. 1: Difference between classical and fuzzy spatial relation input variables (Left: Classical set, right: Spatial relation input variables using fuzzy curves)

Following this notion, fuzzy inference system (FIS), which is a way of mapping an input space to an output space using fuzzy logic. FIS uses a collection of fuzzy membership functions and rules, instead of Binary logic, to reason about data. It is used in the framework to determine the value of quality indicators. Fuzzy inference interprets the values in the input vector based on user pre-defined rules and assigns values to the output vector as shown in fig. 2. Inputs are the parameters that could be taken into consideration while designing a layout configuration. For instance, the different parameters of the space such as dimensions, area, volume, window dimensions, window area, door dimensions and door area for a given space can be inputs for fuzzy system. Output is the space quality indicator value, which fluctuates between 0 -the lowest and 1 -the highest. It denotes the degree of preferability of space and its elements. It can be numerically formulated with ‘indicator’ in fuzzy Mathematics. When the space dimensions, area and volume reach the standard values, the output value of the space quality indicator will increase. When the input and output are granulated with membership functions (MFs: fuzzy subsets) conditional statements between them are written in the following form: If (input is MF x), then (output is MF y), like: “If the area is medium, then the space quality value is very high”, “If the area is small, then the space quality value is very low”, “If the area is large, then the space quality value is medium” as shown in fig. 3. Generally, more than one input is in the operation, and they are connected by logical operators (and, or not) where needed. The parameters and rules are not fixed, and they change to suit different layout configuration designs, which prompt the flexibility of the framework. The inference process determines an output by evaluating each rule, and the final output of the FIS is the weighted average of all rule outputs. In this way, each given space layout configuration has an indicator at the end, expressing their quality value. When the overall calculation process is completed, a list of outputs quality indicators is produced for each space and for overall layout configuration [1] [5].

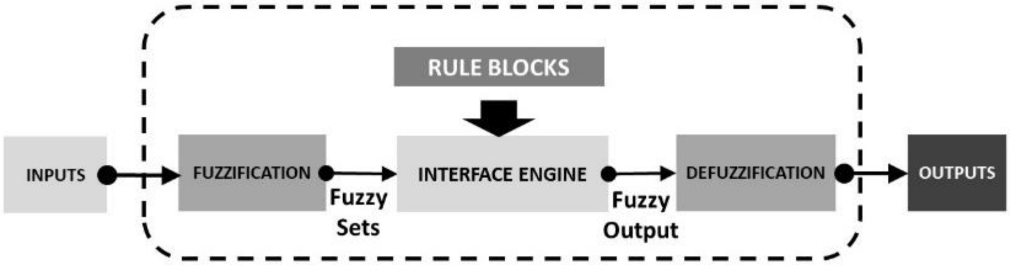



Fig. 2: Fuzzy Interface System (FIS) illustration diagram

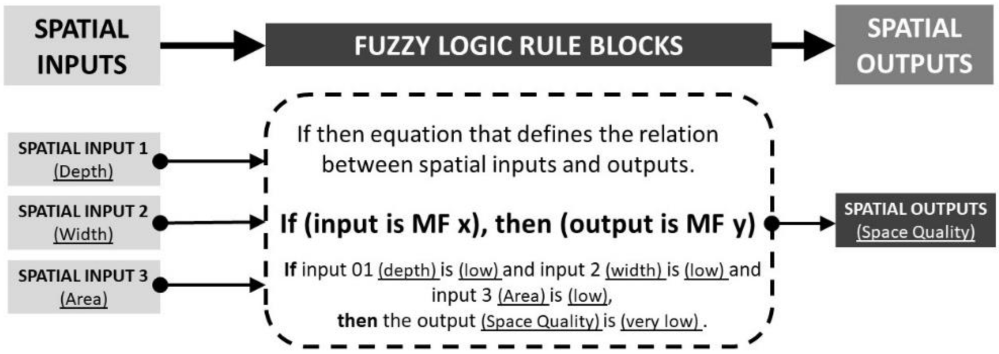



Fig. 3: Fuzzy logic workflow and Rule blocks in fuzzy logic system

## 3. Research methodology and Limitations

This Research is relied on an explorative analysis using an inductive approach trying to propose structure a conceptual framework of automated evaluation of architectural spatial configurations using fuzzy logic approach. To achieve this framework, Firstly, the research reviewed the Current design evaluation tools –DQI, DEEP, AEDET, BREEAM, LEED and BQA, to be able to explore the different factors that affect Space layout planning (SLP). Secondly, extracting spatial inputs based on architectural standards. Moreover, defining spatial outputs based on similar design evaluation tools. Thus, we can define rule blocks which define the relation between inputs and outputs. Consequently, we can propose a full framework based on fuzzy logic-based approach that consists of Inputs, outputs and rules block which define the relation between them, to be able to evaluate the design.
the limitation of this paper pertains to building typology. We would propose a fuzzy system relatively simple and arbitrary residential spaces. Other building typologies and spaces have their complexities and will affect the nature and understanding of the described spatial inputs, outputs, and rule blocks, and hence the nature of the evaluation process itself. Scale of the individual spaces is also a significant factor and potential. The relations described in this paper, although demonstrated in the context of a small residential apartment, can be applied in principle to different scales, levels of detail, and relations, including but not limited to

furniture layout schemes in different spatial typologies, departmental spaces and zones, vertically stacked spaces in building configurations, urban neighborhoods, and clusters, etc.

## 4. Approach

To propose a fuzzy-based approach for the automated evaluation of architectural spatial configurations. We adopted the concept of design quality, more specifically, identifying the overall quality of design requirements for a given spatial layout configuration, such that spatial layout alternates can be evaluated comprehensively in a way that addresses the intended purpose (e.g. how is the functionality, build quality and impact) while considering trade-offs between multiple (non-homogeneous) spatial parameters that designers might not be necessarily aware of during the complex process of design. The basic workflow of using fuzzy based approach is consisting of three main steps (Spatial Inputs, Spatial Outputs & Rule Blocks) as shown in figure 3. It's needed to identify the basic constituents affecting the spatial criteria, we introduce notations for specific space entities that are perceived to inform the logic of the specifics of partial relations, inputs and outputs outlined in the next sections during the fuzzification and defuzzification process as well. Our basic assumption for these entities involved simple layout configurations for multiple spaces joined together to consisting of the layout configuration each of these spaces has openings on it as door and window. These include parameters such as space dimensions, area, center, corner points, door and window location and dimensions, viewing angles to and from the space, and some spatial relations between these spaces etc. Other entities including vertical circulation elements, internal walls and others are out of the scope and will be addressed in future work.

## 5. Spatial Inputs

To introduce the spatial layout configuration and the spatial relation between the spaces through the inputs and outputs, according to fuzzy logic rules, first we need to define the space and its elements that construct the space and their variables which are seen to inform space to space relations and spaces configuration in the fuzzification and defuzzification process. To initiate fuzzification, two levels of spatial input variables are created, and their associated fuzzy sets and membership functions based on the defined space entity notations as well. Firstly, Spatial input level Zero which is the definition of space entities. Secondly, spatial input level one which describes the function of the space, the spatial configuration between these spaces and the relation between the space and context. The codes for these Spatial input variables, calculation method and fuzzy sets will be described in detail in this part. The figure plots membership functions for the fuzzy sets (or descriptors) for all variables. Combination of these variables is used to define rule blocks and identify spatial outputs for a given layout configuration. Each of these variables computes a specific parameter for a given space. We identified the following sets of entities for a given space (ST), like the centroid of the space, corners of the space, lines between these corners, volume, and all openings in this volume.

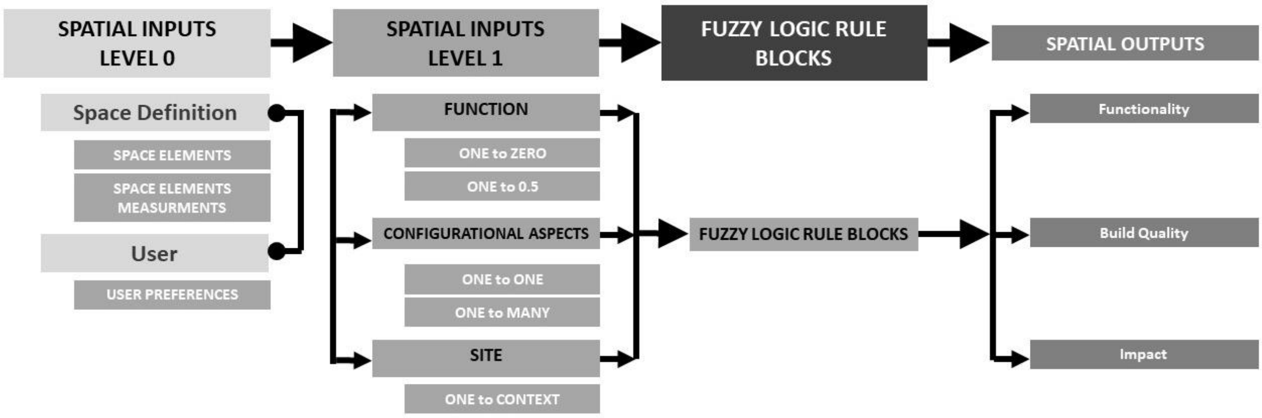



Fig. 4: The modified workflow of using fuzzy logic approach

## 5.1. Spatial Inputs Level Zero

To introduce Spatial input, level zero is the first level of spatial inputs and can be defined as the pre-defined inputs variables which are used to define the space and its entities [6].

### *5.1.1. Defining Space Elements*

The space elements parameters related to the basic definition of the space such as center point, corner points, lines of the walls, the volume, the openings to create a space and the parameters of this space such as the dimensions, area, volume, window dimensions, window area, door dimensions and door area for a given space. Notations include "Space center" (CS), "Space corners" (CR), "Space Lines" (L), "Space Volume" (V) and "Space Openings" (WD, DR). these parameters assumed based on the space elements in (form, space, and order) [15].

**Table 3: Space elements as spatial inputs level zero definitions**

| Space Elements | | | |
|---|---|---|---|
| Spatial Input | | Code | Definition |
| A | IN0_001_CENTER | CS | Centre of space |
| B | IN0_002_CORNERS | CR | Corners of space |
| C | IN0_003_LINES | L | Lines of space |
| D | IN0_004_VOLUME | V | Volume of space |
| E | IN0_005_OPENING | DR & WD | Door & window opening |

### *5.1.2. Definition of The Space*

the space elements definition parameters related to the basic definition of the space include the space type, dimensions, area, volume, window dimensions, window area, door dimensions and door area for a given space. Notations include "Space Type" (ST), "Space dimensions" (W, D, H), "Space Area" (A), "Space Volume" (V), "window dimensions" (WD_W, WD_H), "window Area" (WD_A), "Door dimensions" (DR_W, DR_H) and "Door Area" (DR_A). these parameters assumed based on architectural standards for spaces (Time Saver [16][17], neufert [18], and metric handbook [19]). Descriptors (or "fuzzy sets") were identified for these variables to describe spatial input based on the computed method. For example, "low", "medium" and "high" descriptors were used to describe space area. "Squarish," "rectangular" and "linear" configuration descriptors were used to describe space proportion. A "membership function" was used to define each descriptor based on the associated degree of membership of the linguistic term for any value of the spatial input variable. A collective graph is typically used to visualize the membership functions of all descriptors for a given input variable [5].

**Table 4: Space elements as spatial inputs level zero illustration diagrams**

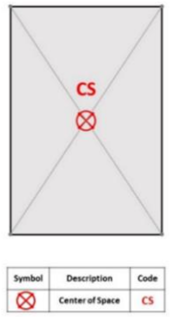
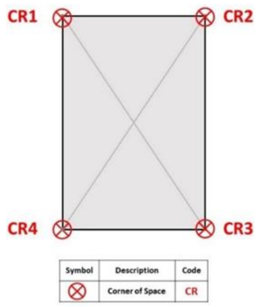
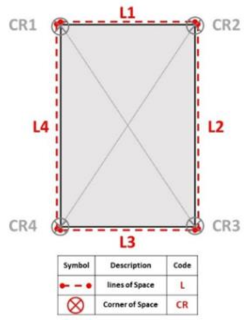
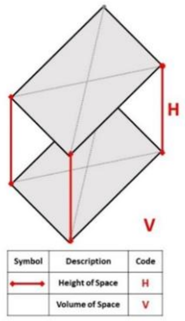
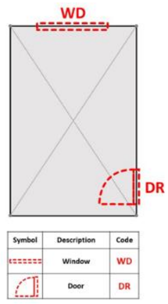
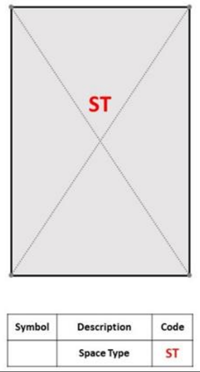
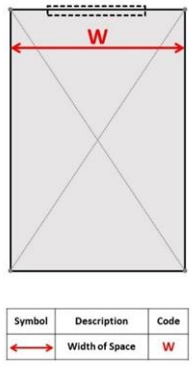
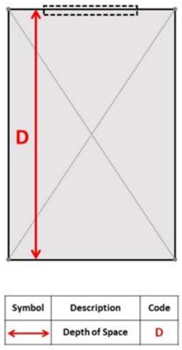
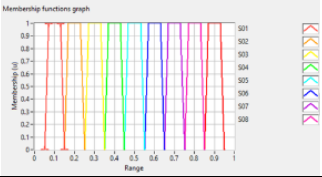
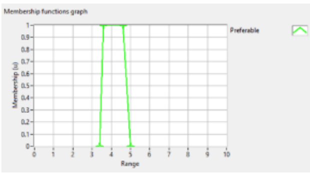
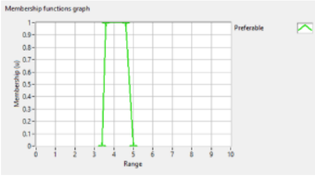
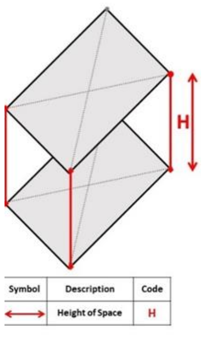
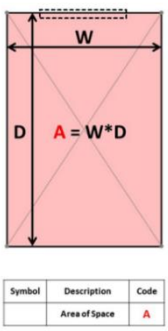
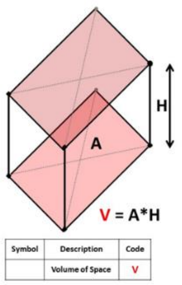
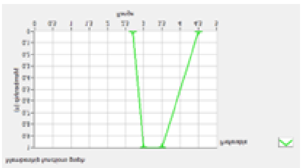
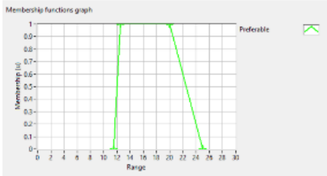
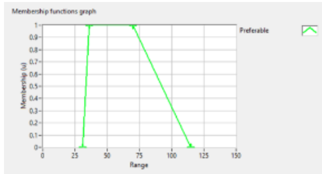
| IN0_001_CENTER | IN0_002_CORNERS | IN0_003_LINES |
|---|---|---|
|  |  |  |
| **IN0_004_VOLUME** | **IN0_005_OPENING** | |
|  |  | |

**Table 5: Space definition as spatial inputs level zero definitions**

| Space Definition | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Spatial Input | Code | definition | Calculation method | unit | Fuzzy sets | |
| A | IN0_101_SPACE TYPE | ST | Define the type of space | | | | |
| B | IN0_102_WIDTH | W | Width of space | | m | Preferable | Unpreferable |
| C | IN0_103_DEPTH | D | Depth of space | | m | Preferable | Unpreferable |
| D | IN0_104_HEIGHT | H | Height of space | | m | Preferable | Unpreferable |
| E | IN0_105_AREA | A | Area of space | A = W * D | m 2 | Preferable | Unpreferable |
| F | IN0_106_VOLUME | V | Volume of space | V = A * H | m 3 | Preferable | Unpreferable |
| G | IN0_107_WINDOW WIDTH | WD_W | Window width | | m | Preferable | Unpreferable |
| H | IN0_108_WINDOW HEIGHT | WD_H | Window height | | m | Preferable | Unpreferable |
| I | IN0_109_WINDOW AREA | WD_A | Widow area | WD_A = WD_W *WD_H | m 2 | Preferable | Unpreferable |
| J | IN0_110_DOOR WIDTH | DR_W | Door width | | m | Preferable | Unpreferable |
| K | IN0_111_DOOR HEIGHT | DR_H | Door height | | m | Preferable | Unpreferable |
| L | IN0_112_DOOR AREA | DR_A | Door area | DR_A = DR_W *DR_H | m 2 | Preferable | Unpreferable |

**Table 6: Space definition as spatial inputs level zero illustration diagrams and fuzzy curves**

| IN0_101_SPACE TYPE | IN0_102_WIDTH | IN0_103_DEPTH |
|---|---|---|
|   |   |   |
|   |   |   |
| IN0_104_HEIGHT | IN0_105_AREA | IN0_106_VOLUME |
|   |   |   |
|  |   |   |
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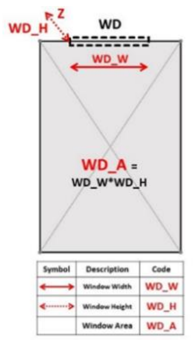
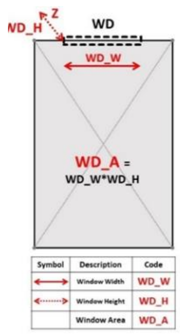
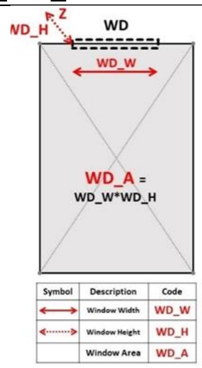
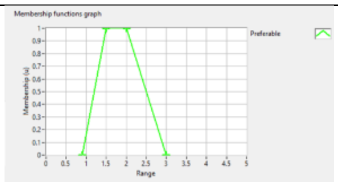
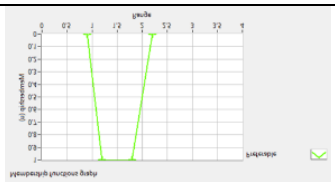
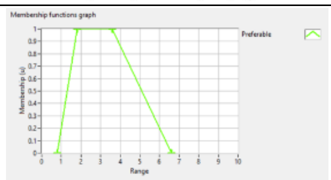
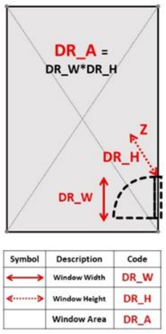
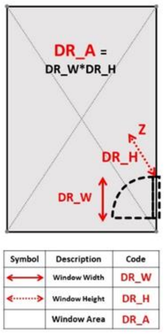
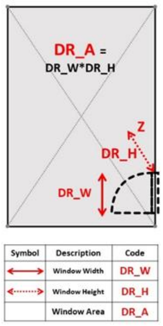
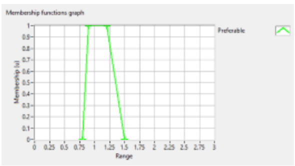
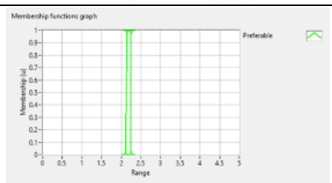
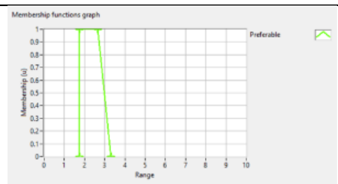
|   |   |   |
|   |  |   |

| IN0_110_DOOR WIDTH | IN0_111_DOOR HEIGHT | IN0_112_DOOR AREA |
|---|---|---|
|  |  |  |
|  |  |  |

## 5.2. Spatial Inputs Level One

Spatial input level one is the second level of spatial inputs and can be defined as the spatial inputs variables which are used to define the different types of relations inside the same space, between two spaces or more, and between the space and the context.

### *5.2.1. Defining Function (One to Zero)*

Function parameters are the relation between the space and its properties. These parameters are related to the area, volume, proportion, angles, distortion, window area ratio, free walls, position, columns, colors, texture, and furniture for a given space. Notations include "Area" (A), "Volume" (V), "proportion" (PS), "Angles" (AN), "Distortion" (DS), "Window Area Ratio" (WDAR), "Free Walls" (FW), "position of space" (EXSP, INSP). these parameters assumed based on architectural standards for spaces (Time Saver [16][17], neufert [18], and metric handbook [19]).

**Table 7: Function as spatial inputs level one to zero definitions**

| | ONE to ZERO | | | | | |
|---|---|---|---|---|---|---|
| | **Spatial Input** | **Code** | **definition** | **unit** | **Fuzzy sets** | |
| A | IN1_001_AREA_SPACE | A | Area of space | m 2 | Preferable | Unpreferable |
| B | IN1_002_VOLUME_SPACE | V | Volume of space | m 3 | Preferable | Unpreferable |
| C | IN1_003_PROPORTION_SPACE | PS | Proportion of space | | Preferable | Unpreferable |
| D | IN1_004_ANGLES_SPACE | AN | Angles of space | degree | Preferable | Unpreferable |
| E | IN1_005_DISTORTION_SPACE | DS | Distortion of space | - | Preferable | Unpreferable |
| F | IN1_006_WINDOW AREA RATIO_SPACE | WDAR | Window area ratio | - | Preferable | Unpreferable |
| G | IN1_007_FREE_WALLS | FW | Number of free walls | - | Preferable | Unpreferable |
| H | IN1_008_external internal POSITION_SPACE | EIPS | Define the position of space external or internal | - | Preferable | Unpreferable |

**Table 8: Function as spatial inputs level one to zero illustration diagrams and fuzzy curves**

<table>
<tr><td>IN1_001_AREA_SPACE</td><td>IN1_002_VOLUME_SPACE</td><td>IN1_003_PROPORTION_SPACE</td></tr>
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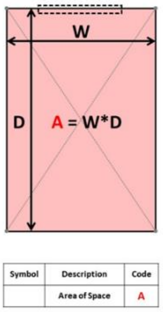
<td>
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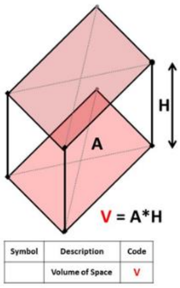
<td>
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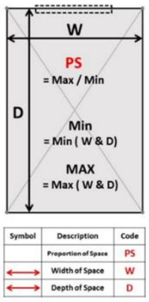
<td>
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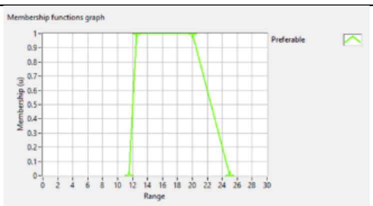
<td>
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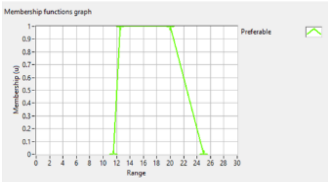
<td>
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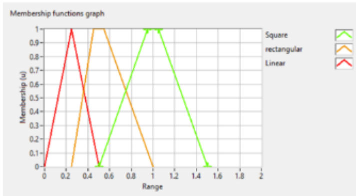
<td>
</td>
</tr>
<tr><td>IN1_004_ANGLES_SPACE</td><td>IN1_005_DISTORTION_SPACE</td><td>IN1_006_WINDOW AREA RATIO_SPACE</td></tr>
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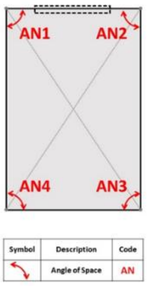
<td>
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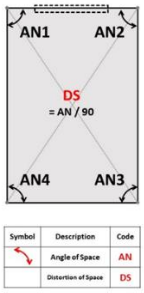
<td>
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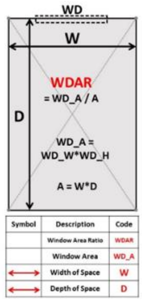
<td>
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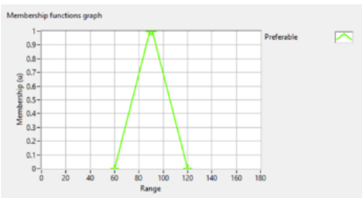
<td>
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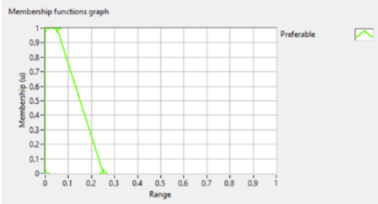
<td>
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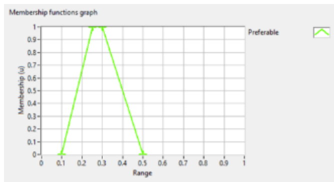
<td>
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<tr><td>IN1_007_FREE_WALLS</td><td>IN1_008_external internal POSITION_SPACE</td><td></td></tr>
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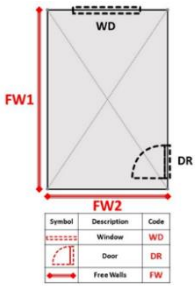
<td>
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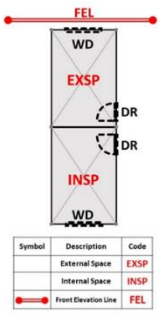
<td>
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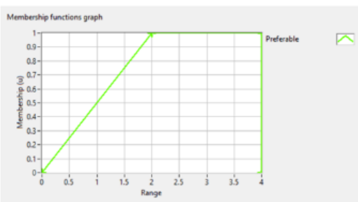
<td>
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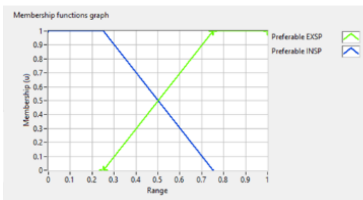
<td>
</td>
<td></td>
</tr>
</table>

### *5.2.2. Defining Function (One to Half)*

Function parameters are the relation between the space and its properties. These parameters are related to the area, volume, proportion, angles, distortion, window area ratio, free walls, position, columns, colors, texture, and furniture for a given space. Notations include "columns" (COLM), "Color elements" (COLR), "Texture Elements" (TXTR) and "Furniture" (FURN).

**Table 9: Function as spatial inputs level one to half definitions**

| Function - One to Half | | | | | | |
|---|---|---|---|---|---|---|
| **Spatial Input** | **Code** | **definition** | **unit** | **Fuzzy sets** | | |
| IN1_101_COLUMNS | COLM | Regularity of Columns module | - | low | medium | high |
| IN1_102_COLORS_ELEMENTS | COLR | the colors of the elements of the space | - | low | medium | high |
| IN1_103_TEXTURE_ELEMENTS | TXTR | the texture of different elements of the space | - | low | medium | high |
| IN1_104_FURNITURE | FURN | the texture of different elements of the space | - | low | medium | high |

### *5.2.3. Defining Spatial Configuration (ONE to ONE)*

Spatial configuration parameters are the relation between two spaces. these parameters are related to center to center, closest corner to corner, the farthest corner to corner, door to door, center door to door center, total center to corner, attached wall length, total area, bounding area, area bounding area ratio, offset curve, isovest area, center door to door center angle for a given spaces. Notations include "center to center" (CSTCS), "closest corner to corner" (CCRCR), "farthest corner to corner" (FCRCR), "door to door" (DRDR), "center door to door center" (CDDC), "total center to corner" (TCSCR),"attached wall length" (ATWL), "total area" (TA), "bounding area" (BA), "area bounding area ratio" (ABAR),"offset curve" (OFFC), "isovest area" (ISOVA), "center door to door center angle" (CDDCA).

**Table 10: Spatial Configuration as spatial inputs level one to half definitions**

| Spatial configuration – one to one | | | | | | |
|---|---|---|---|---|---|---|
| **Spatial Input** | **Code** | **definition** | **unit** | **Fuzzy sets** | | |
| IN1_201_CENTER_TO_CENTER | CSTCS | the length between the center to center of the spaces | m | low | medium | high |
| IN1_202_CLOSEST_CORNER_TO_CORNER | CCRCR | the length between the closest corners of the spaces | m | low | medium | high |
| IN1_203_FARTHEST_CORNER_TO_CORNER | FCRCR | the length between the farthest corners of the spaces | m | low | medium | high |
| IN1_204_DOOR_TO_DOOR | DRDR | the length between the doors of the spaces | m | low | medium | high |
| IN1_205_CENTER_DOOR_DOOR_CENTER | CDDC | the length between the centers to door to door to center of the spaces | m | low | medium | high |
| IN1_206_TOTAL_CENTER_TO_CORNER | TCSCR | the total length between the center and the corner of the spaces | m | low | medium | high |
| IN1_207_ATTACHED_WALL_LENGTH | ATWL | the length of the attached wall between the spaces | m | low | medium | high |

| Spatial configuration – one to one | | | | | | |
|---|---|---|---|---|---|---|
| **Spatial Input** | **Code** | **definition** | **unit** | **Fuzzy sets** | | |
| IN1_208_TOTAL AREA | TA | the total area of the spaces | m2 | low | medium | high |
| IN1_209_BOUNDING_AREA | BA | the bounding area of the spaces | m2 | low | medium | high |
| IN1_210_AREA_BOUNDING_AREA_RATIO | ABAR | the area bounding area ratio | m2 | low | medium | high |
| IN1_211_OFFSET_CURVE | OFFC | the number of offset curves that contain the other space | - | low | medium | high |
| IN1_213_ISOVEST AREA | ISOVA | the isovest area of the space | m2 | low | medium | high |
| IN1_215_CENTER DOOR DOOR CENTER ANGLE | CDDCA | the angle between the center to door door center of the spaces | degree | low | medium | high |

**Table 11: Spatial Configuration as spatial inputs level one to half illustration diagrams and fuzzy curves**

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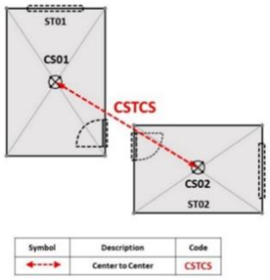
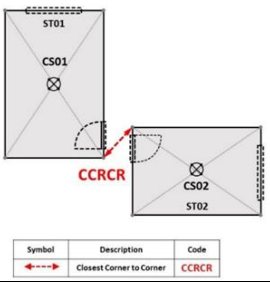
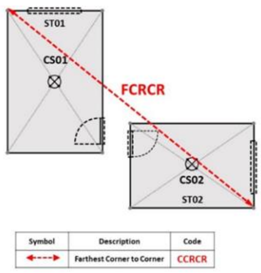
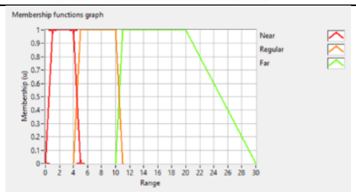
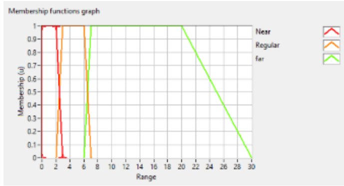
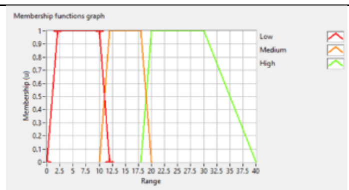
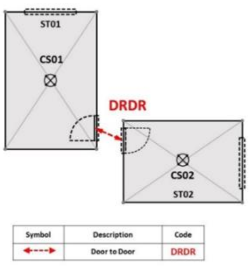
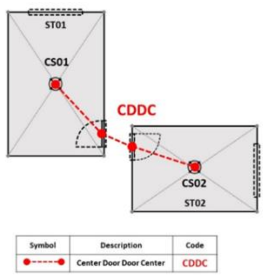
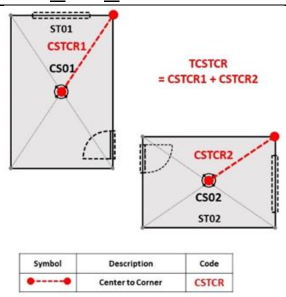
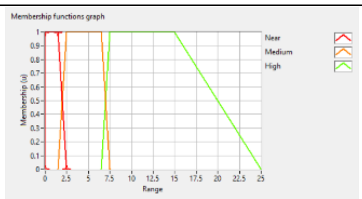
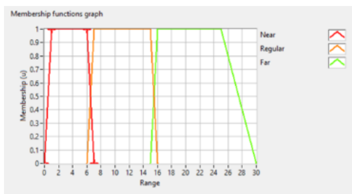
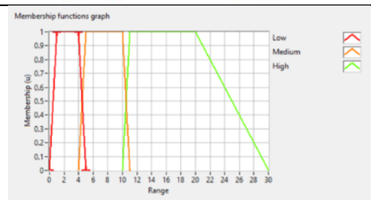
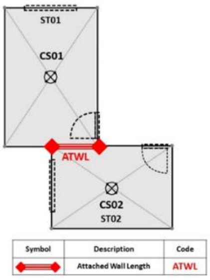
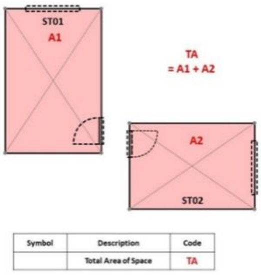
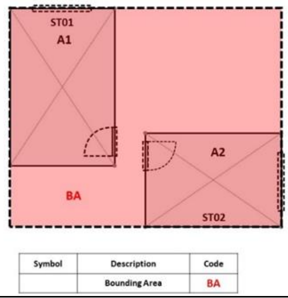
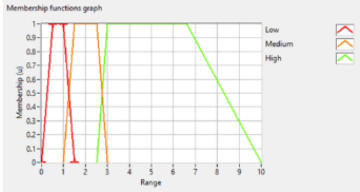
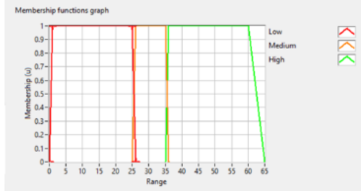
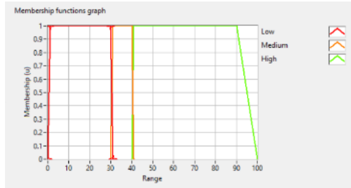
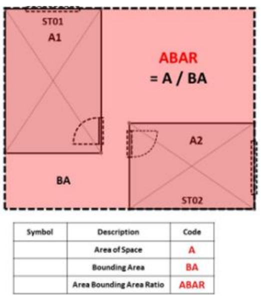
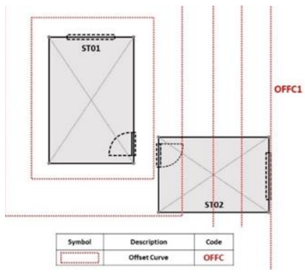
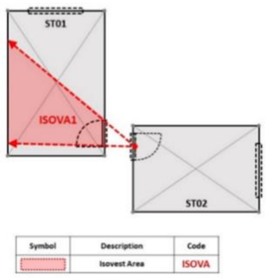
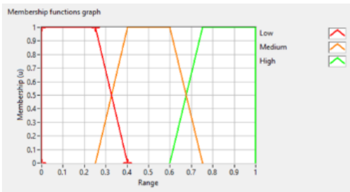
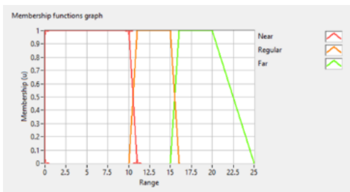
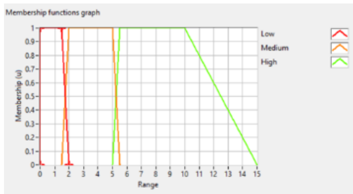
|---|---|---|
|  |  |  |
|  |  |  |
| IN1_204_DOOR_TO_DOOR | IN1_205_CENTER_DOOR_ DOOR_CENTER | IN1_206_TOTAL_CENTER _TO_CORNER |
|  |  |  |
|  |  |  |
| IN1_207_ATTACHED _WALL_LENGTH | IN1_208_TOTAL AREA | IN1_209_BOUNDING_AREA |

| | | |
|---|---|---|
|  |  |  |
|  |  |  |
| IN1_210_AREA_BOUNDING _AREA_RATIO | IN1_211_OFFSET_CURVE | IN1_213_ISOVEST AREA |
|  |  |  |
|  |  |  |

### 5.2.4. *Defining the spatial configuration (ONE to MANY)*

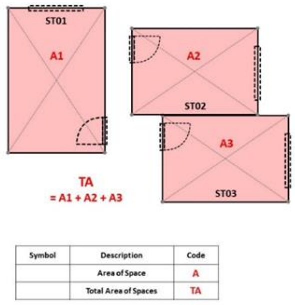
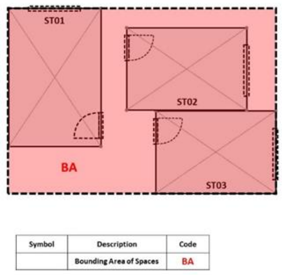
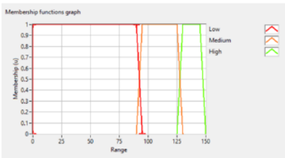
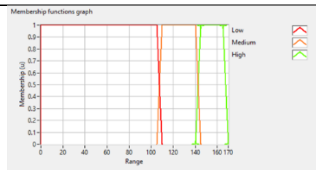
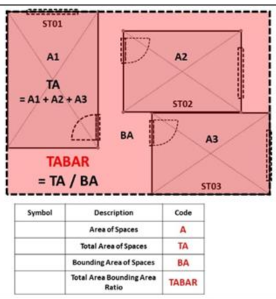
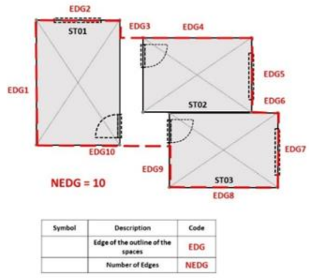
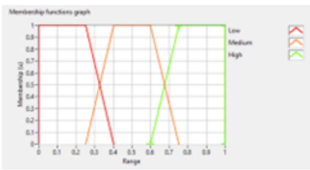
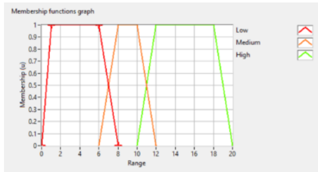
Spatial configuration parameters are the relation between many spaces. These parameters are related to total area, bounding area, area bounding area ratio, number of edges, configuration, depth of spaces and privacy for a given spaces. Notations include “total area” (TA), “bounding area” (BA), “area bounding area ratio” (ABAR), “number of edges” (NOE), “configuration” (CONF), “depth of space” (DEPSP) and “privacy” (PRIVSP).

**Table 12: Spatial Configuration as spatial inputs level one to half definitions**

| **Spatial Configuration - One to Many** | | | | | | |
|---|---|---|---|---|---|---|
| **Spatial Input** | **Code** | **definition** | **unit** | **Fuzzy sets** | | |
| IN1_301_TOTAL AREA | TA | the total area of the spaces | m 2 | low | medium | high |
| IN1_302_BOUNDING AREA | BA | the bounding area of the spaces | m 2 | low | medium | high |
| IN1_303_AREA BOUNDING AREA RATIO | TABAR | the area bounding area ratio | - | low | medium | high |
| IN1_304_NUMBER OF EDGES | NOE | the number of edges | - | low | medium | high |
| IN1_305_CONFIGURATION | CONF | the configuration of the spaces | - | low | medium | high |

| Spatial Configuration - One to Many | | | | | | |
|---|---|---|---|---|---|---|
| **Spatial Input** | **Code** | **definition** | **unit** | **Fuzzy sets** | | |
| IN1_306_DEPTH SPACES | DEPSP | Degree of depth of the space | - | low | medium | high |
| IN1_307_PRIVACY | PRIVSP | Degree of privacy of the space | - | low | medium | high |

**Table 13: Spatial Configuration as spatial inputs level one to half illustration diagrams and fuzzy curves**

| IN1_301_TOTAL AREA | IN1_302_BOUNDING AREA |
|---|---|
|  |  |
|  |  |
| IN1_303_AREA BOUNDING AREA RATIO | IN1_304_NUMBER OF EDGES |
|  |  |
|  |  |









## 5.2.5. *Defining the site (ONE to CONTEXT)*

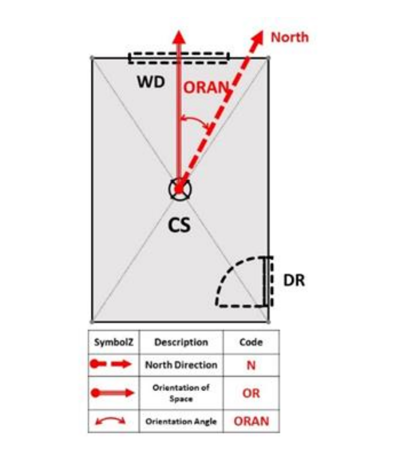
Site parameters are the relation between the space and the context. These parameters are related to orientation, viewing angle, external opening, external solid, void ratio, solid ratio, and void solid ratio for a given space. Notations include “orientation” (ORAN), “viewing angles” (VWAN), “external opening” (EXVO), “external solid” (EXSO), “void ratio” (VORT), “solid ratio” (SORT) and “void solid ratio” (VOSOR).

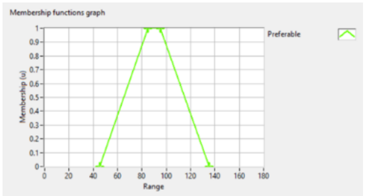
**Table 14: Site as spatial inputs level one to context definitions**

| SPATIAL CONFIGURATION - ONE TO MANY – SPATIAL INPUTS LEVEL ONE | | | | | |
|---|---|---|---|---|---|
| **Spatial Input** | **Code** | **definition** | **unit** | **Fuzzy sets** | |
| A. IN1_401_ORIENTATION | ORAN | The angle of the orientation of the spaces | degree | Preferable | Unpreferable |
| B. IN1_402_VIEWING_ANGLES | VWAN | the viewing angles of the spaces | degree | Preferable | Unpreferable |
| C. IN1_403_EXTERNAL OPENINGS | EXVO | the external area of the spaces | m 2 | Preferable | Unpreferable |
| D. IN1_404_EXTERNAL SOLIDS | EXSO | the external solids of the spaces | m 2 | Preferable | Unpreferable |
| E. IN1_405_VOID RATIO | VORT | the void ratio of the spaces | - | Preferable | Unpreferable |
| F. IN1_406_SOLID RATIO | SORT | the solid ratio of the spaces | - | Preferable | Unpreferable |
| G. IN1_407_VOID SOLID RATIO | VOSOR | the solid void ratio of the spaces | - | Preferable | Unpreferable |

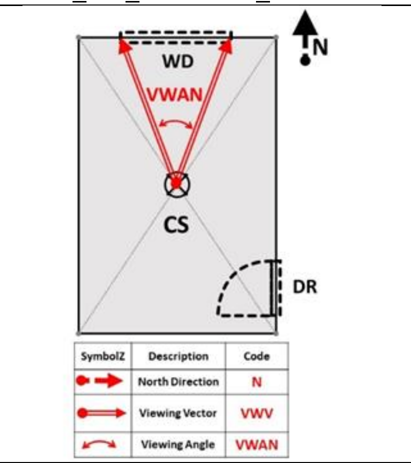
**Table 15: Site as spatial inputs level one to context definitions**

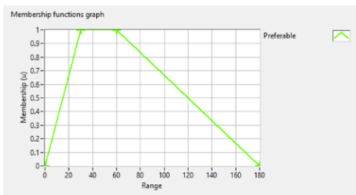
IN1_401_ORIENTATION



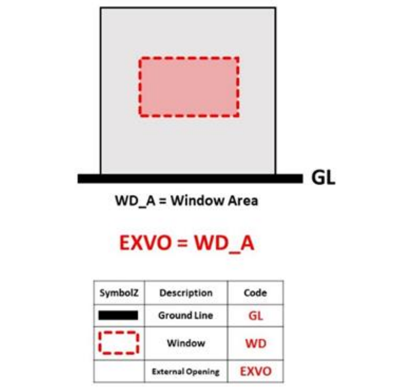



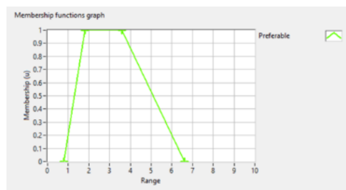

IN1_402_VIEWING_ANGLES



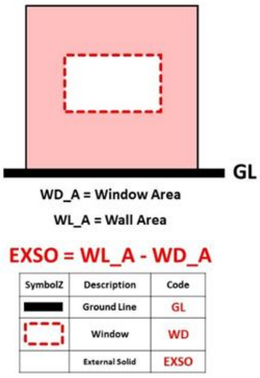




IN1_403_EXTERNAL OPENINGS

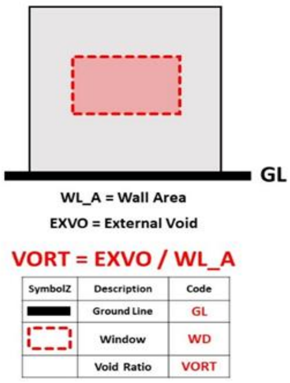


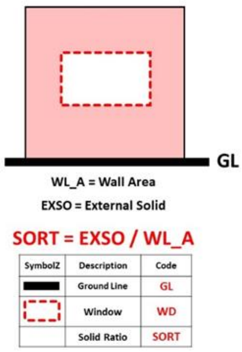

IN1_404_EXTERNAL SOLIDS

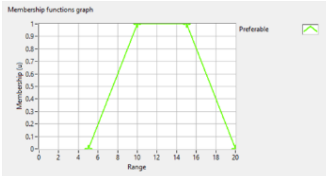
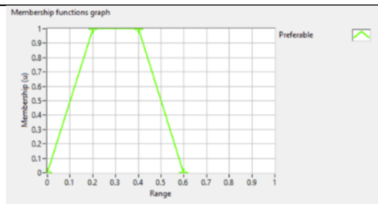
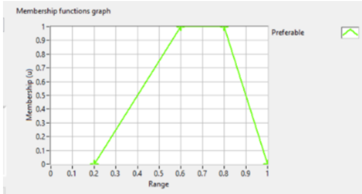
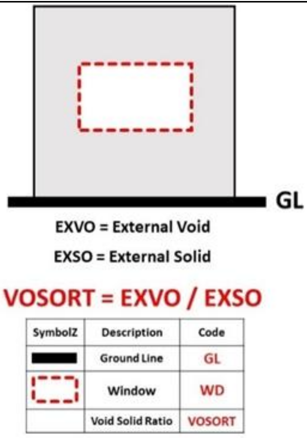
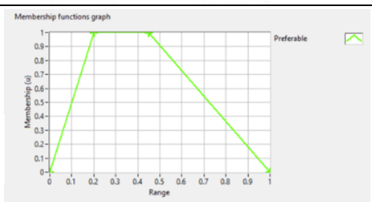



IN1_405_VOID RATIO




IN1_406_SOLID RATIO



| | | |
|---|---|---|
|  |  |  |
| IN1_407_VOID SOLID RATIO | | |
|  | | |
|  | | |

## 6. Spatial Output Qualities

For the defuzzification process, we identified spatial output variables and their associated fuzzy sets and membership functions. Design Quality Indicator (DQI) three quality fields separated into (Functionality, build quality, and Impact) [14], based on these qualities we developed our definition of variables for spatial outputs. These variables describe three main outputs categories:

- Outputs for Functionality (including Space Elements, Space, Use, Location, Access, Spatial Relations, Adjacency and Non-Adjacency & Proximity)
- Outputs for Build quality (including Performance, Efficiency, Engineering, Construction and Cost)
- Outputs for Impact (Including user preferences, form material, internal environment, urban Integration, Society and Culture).

Descriptors (or “fuzzy sets”) were identified for these variables to describe the spatial output based on the computed method. For example, “accepted” and “not-accepted” descriptors were used to describe “Functionality of space.” A “membership function” was used to define each descriptor based on the associated degree of membership of the linguistic term for any value of the spatial output variable. A collective graph is typically used to visualize the membership functions of all descriptors for a given output variable.

## 6.1. Functionality

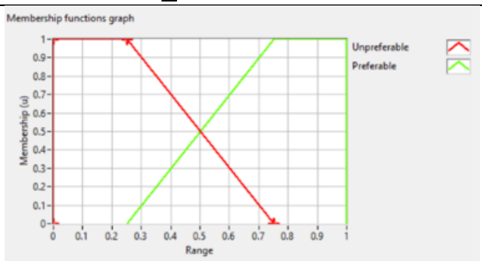
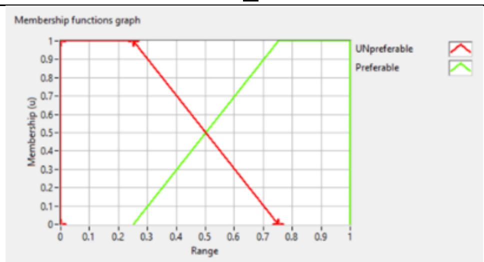
Functionality is considered as one of spatial outputs. This spatial quality is the indicator for the quality of space elements, the space itself, spatial relation between the spaces and the spatial relation between the space and the context. These parameters are related to space elements, space, use, Location, Access, Adjacency, Non-Adjacency, Proximity & Spatial Relations for the given spaces.

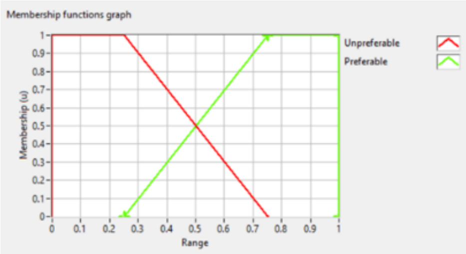
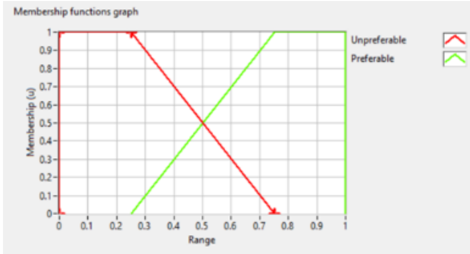
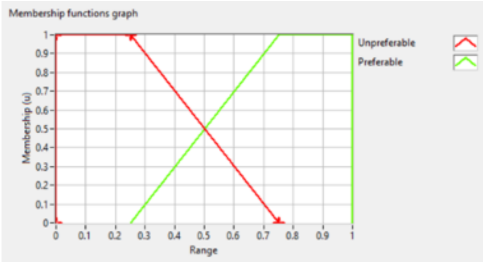
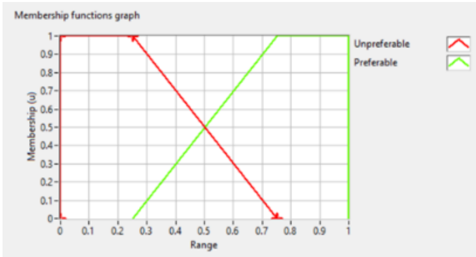
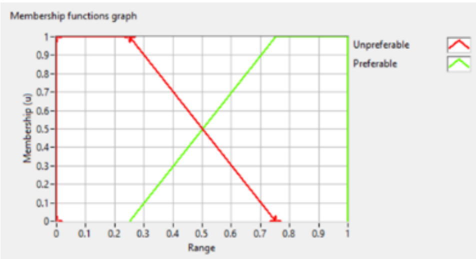
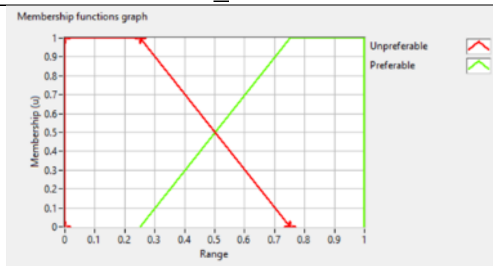
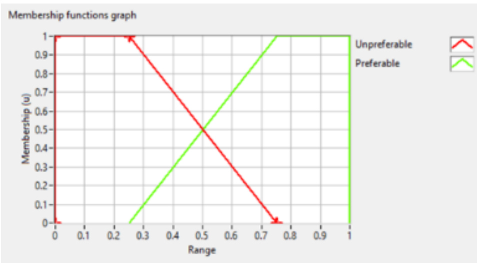
The spatial output variable (OUT101_SPACE ELEMENTS) denotes the degree of acceptance of all space elements including the basic dimensions of the space and the space opening dimensions based on the space type. (OUT102_SPACE) denotes the degree of acceptance of the architectural space. (OUT103_USE) denotes the degree of acceptance of the space according to its use. (OUT104_CONTEXT) denotes the degree acceptance of space according to its relationship with the context. (OUT105_ACCESS) denotes the degree of convenience and comfort regarding physical accessibility from one space to another. (OUT07_Adjacency) denotes the degree of immediacy of space connection in relation to other neighboring spaces. (OUT107_NON-ADJACENCY) denotes the degree of immediacy of space connection in relation to other neighboring spaces. (OUT108_PROXIMITY) denotes the degree of proximity of space connection in relation to other neighboring spaces. (OUT109_SPATIAL_RELATIONS) denotes the degree of physical linkage of one space to other spaces.

**Table 16: Functionality as spatial output definitions**

| Functionality of Space | | | |
|---|---|---|---|
| **Spatial Output** | **Code** | **Fuzzy Sets** | |
| OUT101_SPACE ELEMENTS | SPELEM | Preferable | Unpreferable |
| OUT102_SPACE | SP | Preferable | Unpreferable |
| OUT103_USE | USE | Preferable | Unpreferable |
| OUT104_LOCATION | LOC | Preferable | Unpreferable |
| OUT105_ACCESS | ACS | Preferable | Unpreferable |
| OUT106_ADJACENCY | ADJ | Preferable | Unpreferable |
| OUT107_NON-ADJACENCY | NONADJ | Preferable | Unpreferable |
| OUT108_PROXIMITY | PROX | Preferable | Unpreferable |
| OUT109_SPATIAL_RELATIONS | SPTREL | Preferable | Unpreferable |

**Table 17: Functionality as spatial output fuzzy curves**

| OUT101_SPACE ELEMENTS | OUT102_SPACE |
|---|---|
|  |  |

| OUT103_USE | OUT104_LOCATION |
| --- | --- |
|  |  |
| OUT105_ACCESS | OUT106_ADJACENCY |
|  |  |
| OUT107_NON-ADJACENCY | OUT108_PROXIMITY |
|  |  |
| OUT109_SPATIAL_RELATIONS | |
|  | |

## 6.2. Build Quality

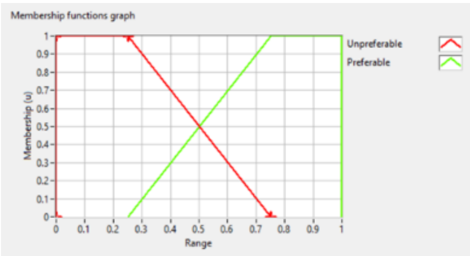
These parameters are related to performance, efficiency, engineering, construction, and cost of the layout configuration. The spatial output variable (OUT201_PERFORMANCE) denotes the degree of acceptance of the measured quality of spaces. (OUT202_EFFICIENCY) denotes the degree of acceptance of the ratio between the desired quality, as spatial output to the spatial inputs. (OUT203_ENGINEERING) denotes the degree of acceptance of the engineering of the spaces. (OUT204_CONSTRUCTION) denotes the degree of acceptance of the construction quality of spaces. (OUT205_COST) denotes the degree of acceptance of the construction cost according to the used construction material and the constructed spaces.

**Table 18: Build Quality as spatial outputs definitions**

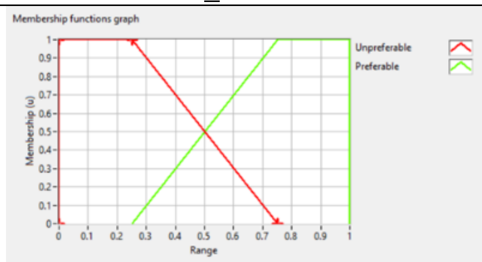
| Build Quality of Space | | | |
|---|---|---|---|
| **Spatial Output** | **Code** | **Fuzzy Sets** | |
| A. OUT201_PERFORMANCE | PERF | Preferable | Unpreferable |
| B. OUT202_EFFICIENCY | EFFIC | Preferable | Unpreferable |
| C. OUT203_ENGINEERING | ENG | Preferable | Unpreferable |
| D. OUT204_CONSTRUCTION | CONST | Preferable | Unpreferable |
| E. OUT205_COST | COST | Preferable | Unpreferable |

**Table 19: Build Quality as spatial outputs fuzzy curves**

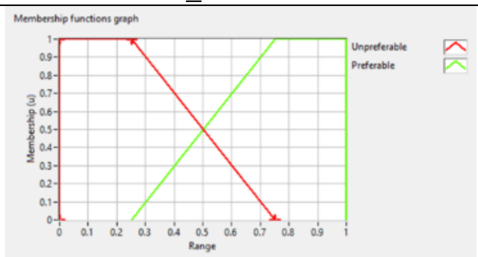
OUT201_PERFORMANCE



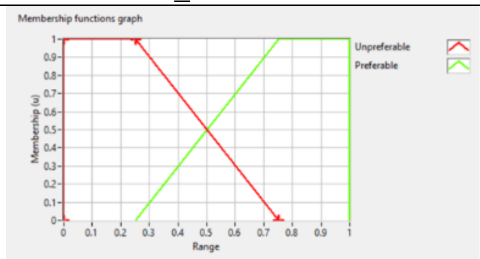

OUT202_EFFICIENCY



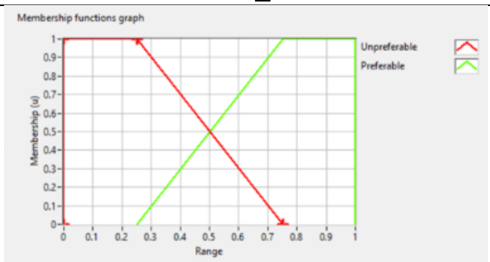

OUT203_ENGINEERING




OUT204_CONSTRUCTION




OUT205_COST



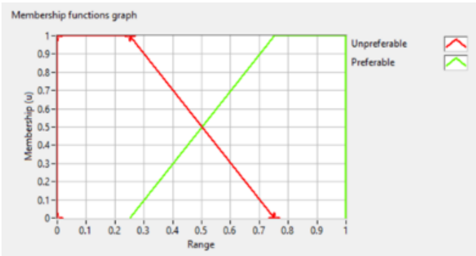
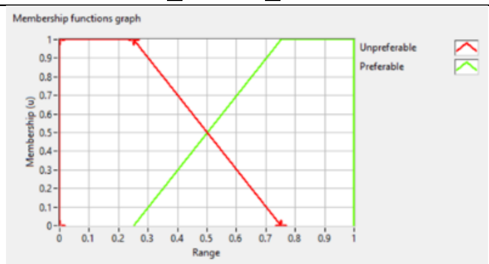
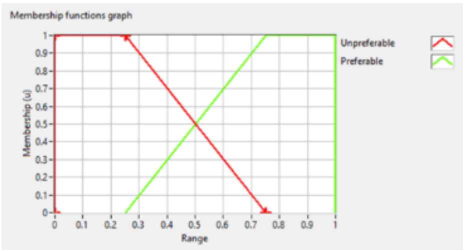
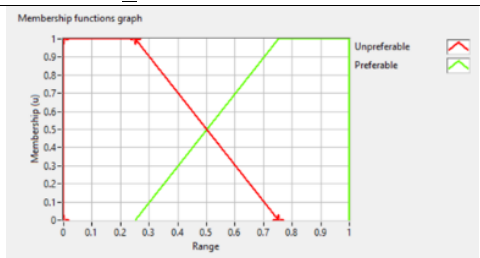
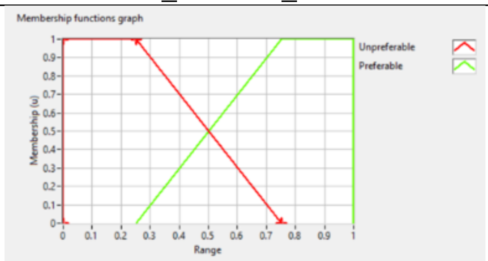

## 6.3. Impact

These parameters are related to user performance, material form, internal environment, urban, social, and cultural integration for the given spaces. The spatial output variable (OUT301_USER_PREFERENCES) denotes the degree of acceptance of the user preferences. (OUT302_FORM_MATERIAL) denotes the degree of acceptance of the architectural form according to the context and the used materials for the facade. (OUT303_INTERNAL ENVIRONMENT) denotes the degree of acceptance of internal environment according to the thermal comfort, air ventilation and daylighting inside the spaces. (OUT304_URBAN INTEGRATIOAN) denotes the degree of acceptance of integration of the space within urban spaces. (OUT305_SOCIAL AND CULTURE) denotes the degree of acceptance of the spaces according to the social aspects of the users and the culture of the community.

**Table 20: Impact as spatial outputs definitions**

| | Impact of Space | | | |
|---|---|---|---|---|
| | **Spatial Output** | **Code** | **Fuzzy Sets** | |
| A | OUT301_USER_PREFERENCES | USRPERF | Preferable | Unpreferable |
| B | OUT302_FORM_MATERIAL | FOMMAT | Preferable | Unpreferable |
| C | OUT303_INTERNAL ENVIRONMENT | INTENVR | Preferable | Unpreferable |
| D | OUT304_URBAN INTEGRATIOAN | URBNINT | Preferable | Unpreferable |
| E | OUT305_SOCIAL_CULTURE | SOCCULT | Preferable | Unpreferable |

**Table 21: Impact as spatial outputs fuzzy curves**

<table>
<tr><td>OUT301_USER preferences</td><td>OUT302_FORM_MATERIAL</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>OUT303_INTERNAL ENVIRONMENT</td><td>OUT304_URBAN INTEGRATIOAN</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>OUT305_SOCIAL_CULTURE</td><td></td></tr>
<tr><td>
</td><td></td></tr>
</table>

## 7. Spatial Rule Blocks

Based on the identified linguistic variables, we devised some rule blocks that control and contribute to the satisfaction of a given spatial output variable by virtue of a combination of different spatial inputs. Rule Block 01 (RB101_SPACE ELEMENTS), for example, demonstrates a rule block that controls the relation between (IN0_101_SPACE TYPE), (IN0_102_WIDTH), (IN0_103_DEPTH), (IN0_104_HEIGHT), (IN0_105_AREA), (IN0_106_VOLUME), (IN0_107_WINDOW WIDTH), (IN0_108_WINDOW HEIGHT), (IN0_109_WINDOW AREA), (IN0_110_DOOR WIDTH), (IN0_111_DOOR HEIGHT) and (IN0_112_DOOR AREA) on the one hand and (OUT101_SPACE ELEMENTS) on the other hand. If the descriptor of the width (IN0_102) is “preferable,” the descriptor of the depth (IN0_103) is “preferable,” the descriptor of the height (IN0_104) is “preferable,” the descriptor of the area (IN0_105) is “preferable,” the descriptor of the volume (IN0_106) is “preferable,” the descriptor of the window height (IN0_107) is “preferable,” the descriptor of the window area (IN0_108) is “preferable, ” the descriptor of the door width (IN0_109) is “preferable,” the descriptor of the door height (IN0_110) is “preferable” and the descriptor of the door area (IN0_111) is “preferable” for a specific space type then the descriptor of the spatial output “SPACE ELEMENTS” (OUT101) is “preferable.” If the descriptor (IN0_102), (IN0_103), (IN0_104), (IN0_105), (IN0_106), (IN0_107), (IN0_108), (IN0_109), (IN0_110) and (IN0_111) however, are “not preferable,” respectively, the descriptor of (OUT101) is “not accepted”. In this case, ten spatial inputs (IN0_102, IN0_103, IN0_104, IN0_105, IN0_106, IN0_107, IN0_108 ,IN0_109, IN0_110 and IN0_111) contributed to the description of one spatial output (OUT101) for (RB101), using two “if then” rules that denote two conditions for evaluating the degree of acceptance of space elements whether to be accepted or not . This is not a typical case; as the result varies depending on the number of spatial input variables, the specific nature of the fuzzy sets and the rules regulating the relation between the spatial input variable(s) and the target spatial output variable. Table 8 shows the structure of the proposed fuzzy logic rule blocks and the relation between 61 spatial input variables and 19 spatial output variables using 19 rule blocks that control the input– output relations.

**Table 22: Rule blocks definitions**

| Functionality | | | |
|---|---|---|---|
| **Spatial Output** | **Code** | **Spatial Inputs** | **Spatial Output** |
| RB101_SPACE ELEMENTS | RB_SPELEM | IN0_101, IN0_102, IN0_103, IN0_104, IN0_105, IN0_106, IN0_107, IN0_108, IN0_109, IN0_110, IN0_111 & IN0_112. | OUT101 |
| RB102_SPACE | RB_SP | IN1_001, IN1_002, IN1_003, IN1_004, IN1_005, IN1_006, IN1_007 & IN1_008 | OUT102 |
| RB103_USE | RB_USE | IN1_001, IN1_002, IN1_003, IN1_004, IN1_005, IN1_006 & IN1_007 | OUT103 |
| RB104_CONTEXT | RB_CONT | IN1_401, IN1_402, IN1_403, IN1_404, IN1_405, IN1_406 & IN1_407 | OUT104 |
| RB105_ACCESS | RB_ACS | IN1_305, IN1_306, IN1_307 | OUT105 |
| RB106_ADJACENCY | RB_ADJ | IN1_201, IN1_202, IN1_203, IN1_204, IN1_205, IN1_206, IN1_207, IN1_208, IN1_209, IN1_210, IN1_211, IN1_113 & IN1_215 | OUT106 |
| RB107_NON-ADJACENCY | RB_NONADJ | IN1_201, IN1_202, IN1_203, IN1_204, IN1_205, IN1_206, IN1_207, IN1_208, IN1_209, IN1_210, IN1_211, IN1_113 & IN1_215 | OUT107 |
| RB108_PROXIMITY | RB_PROX | IN1_201, IN1_202, IN1_203, IN1_204, IN1_205, IN1_206, IN1_207, IN1_208, IN1_209, IN1_210, IN1_211, IN1_113 & IN1_215 | OUT108 |
| RB109_SPATIAL_RELATIONS | RB_SPTREL | IN1_301, IN1_302, IN1_303, IN1_304, IN1_305, IN1_306 & IN1_307 | OUT109 |

| **Build Quality** | | | |
|---|---|---|---|
| **Spatial Output** | **Code** | | |
| RB201_PERFORMANCE | RB_PERF | IN1_102, IN1_103 | OUT201 |
| RB202_EFFICIENCY | RB_EFFIC | IN1_001, IN1_002, IN1_003, IN1_004, IN1_005, IN1_006, IN1_007 & IN1_104 | OUT202 |
| RB203_ENGINEERING | RB_ENG | IN0_107, IN0_108, IN0_110, IN0_111, IN1_003, IN1_004, IN1_005, IN1_101, IN1_303, IN1_304, IN1_305 | OUT203 |
| RB204_CONSTRUCTION | RB_CONST | IN1_003, IN1_004, IN1_101, IN1_301, IN1_302, IN1_303, IN1_304, IN1_305 | OUT204 |
| RB205_COST | RB_COST | IN1_004, IN1_005, IN1_101, IN1_301, IN1_302, IN1_303, IN1_304, IN1_305, IN1_403, IN1_404, IN1_405, IN1_406, IN1_307 | OUT205 |
| **Impact** | | | |
| **Spatial Output** | **Code** | | |
| RB301_USER preferences | RB_USRPERF | IN0_201, IN0_202, IN0_203, IN1_008, IN1_307 | OUT301 |
| RB302_FORM_MATERIAL | RB_FOMMAT | IN1_401, IN1_402, IN1_403, IN1_404, IN1_405, IN1_406, IN1_407 | OUT302 |
| RB303_INTERNAL ENVIRONMENT | RB_INTENVR | IN0_107, IN0_108, IN0_110, IN0_111, IN0_112, IN1_006, IN1_401, IN1_402, IN1_403, IN1_404, IN1_405, IN1_406, IN1_407 | OUT303 |
| RB304_URBAN INTEGRATIOAN | RB_URBNINT | IN1_401, IN1_402, IN1_403, IN1_404, IN1_405, IN1_406, IN1_407 | OUT304 |
| OUT304_SOCIAL_CULTURE | RB_SOCCULT | | OUT305 |

## 8. The Proposed Framework for Automated Evaluation of Spatial Layout Configuration Using Fuzzy Logic Approach

Our proposed framework for automated evaluation of spatial layout configuration using fuzzy logic approach consists of 4 stages; stage 1: spatial input level zero (space definition [space elements, space elements definition] & user experience) ,stage 2: (Function [one to zero, one to half], Spatial Configuration [one to one, one to many] and site[one to context] ,stage 3: fuzzy logic rules blocks , and stage 4: Spatial outputs[functionality, build quality & impact]. The following diagram illustrates the detailed proposed framework of automated evaluation of spatial layout configuration using fuzzy logic approach

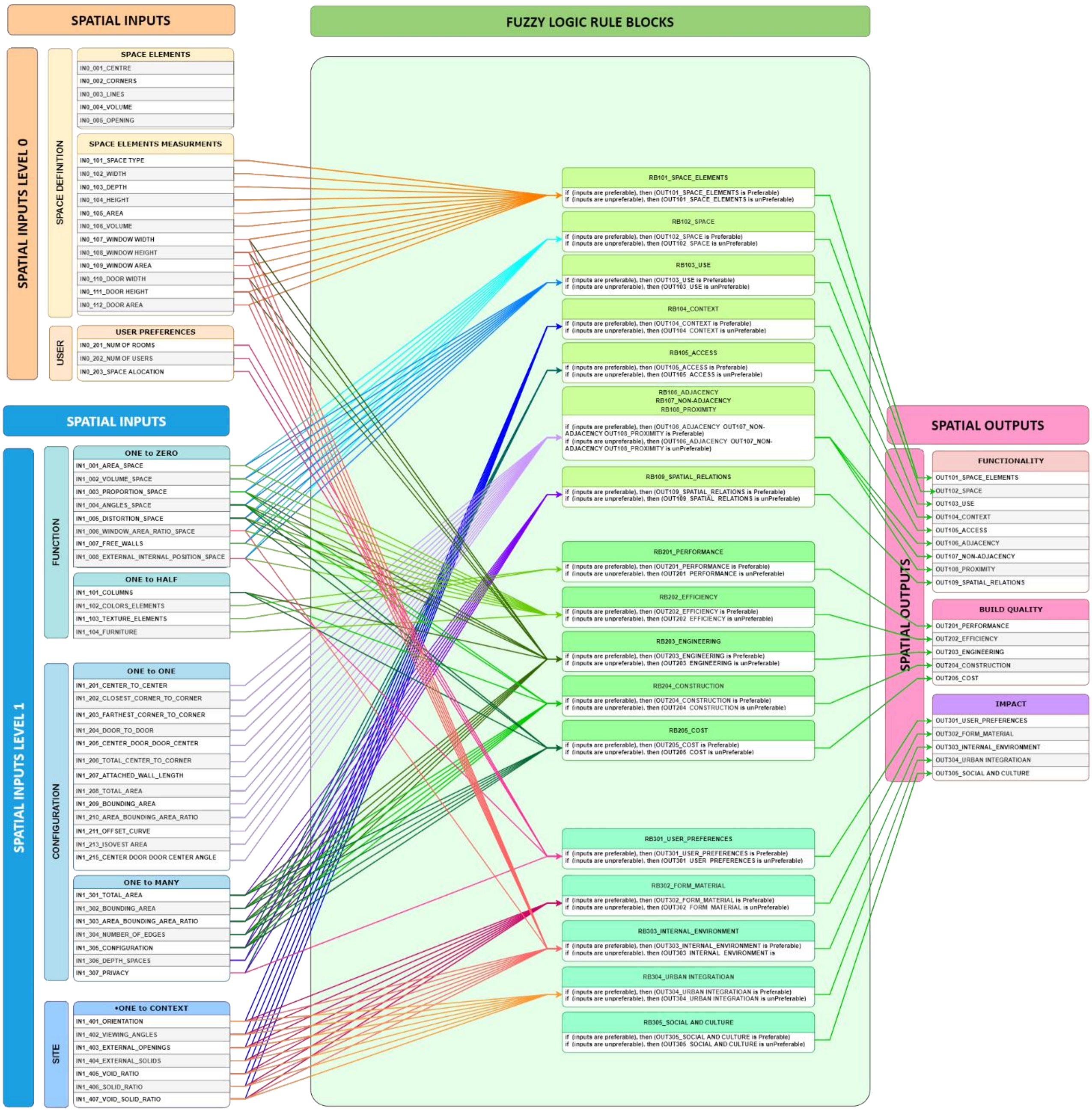



Fig. 7: the detailed proposed framework for automated evaluation for spatial layout configuration using fuzzy logic approach.

## 9. Conclusions

This Architectural spatial layout configurations aim to fulfill various goals which are usually expected to provide solutions transferable into physical volumes and solid environmental components. In the presence of various inputs and goals in the design process the architects and designers started to find it difficult to achieve an absolute success in all the aspects and approaches that should be considered in the design. Consequently, they started to work to achieve the optimum solution to the design problem by balancing all the inputs and constraints to reach the highest percentages of success in all the design objectives. This created the need for the presence of an automated evaluation tool that can comprise all the evaluation criteria needed, moreover considering the design objectives and constraints. This tool should evaluate layout configuration in a precise way showing the percentage of success in each of the design objectives, not a binary evaluation ("weak" or "strong"). In this paper, we created all possible spatial relation inputs affecting physical and non-physical outputs for a given space using descriptive rule blocks in a fuzzy logic software development tool. We use this fuzzy logic system to evaluate different spatial layout configurations. All linguistic input variables, output variables, and fuzzy sets are defined, and space-space relations are presented using membership functions. The resulting database of fuzzy agents is used to evaluate the design process output. This paper introduced a proposed framework for the automated evaluation for spatial layout configuration using fuzzy logic approach to describe the quality of design. The paper attempted to evaluate these qualities by separating them into three main Qualities functionality, build quality & impact and by defining all space elements, calculation methods for spatial inputs, and addressing rule blocks to describe the relations between these inputs and spatial outputs that take into consideration their fuzzy sets or descriptors. In this paper, the relations described can be applied in principle to three different scales, Function [one to zero, one to half], Spatial Configuration [one to one, one to many] and site [one to context]. The paper's findings confirm that using an automated evaluation fuzzy logic-based tool, rather than the conventional spatial relation matrix diagrams that tend to describe those relations holistically as "strong" or "weak" relations, opens the door for the possibility of automating the whole design process of spatial layout configurations, allowing to make use of optimization methodologies to achieve the optimum design solution that reaches the highest percentages in all design objectives. This possible optimized automated design process was not going to be possible without a reliable automated evaluation tool that can build dataset for fuzzy logic and optimization process to work on. For spatial inputs and addressing rule blocks to describe the relations between these inputs and spatial outputs that take into consideration their fuzzy sets or descriptors.

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# منهجية عمل مقترحة للتقييم الآلي للتشكيلات الفراغية المعمارية باستخدام المنطق الرقمي الضبابي

التشكيلات الفراغية المعمارية هي نتاج لعملية تصميم معقدة تهدف إلى تحقيق الموقع الأكثر ملائمة لكل الفراغات المعمارية في إطار مجموعة من الأهداف والقيود المحددة. في ظل وجود توسع بهدف فهم التشكيلات الفراغية ودورها وتكويناتها في العديد من النطاقات البرامجية والأيديولوجية والشكلية والجوانب الهندسية، والمتضمنة في خلفية نظرية معقدة. جانب التقييم هو الأقل وضوحا وهناك قيود كبيرة على ما يمكن تحقيقه فيه. تهدف هذه الورقة إلى تقييم الجوانب الوظيفية (مثل جودة المساحة والاستخدام والوصول والتقارب وعدم التقارب والقرب وما إلى ذلك)، وجودة البناء (مثل الأداء والكفاءة والتكلفة وما إلى ذلك)، والتأثير (مثل أداء المستخدم والجودة الداخلية والتكامل الحضري والاجتماعي والثقافي وما إلى ذلك)، وبالإشارة إلى جودة تصميم الفراغات المعمارية وجودة التشكيلات الفراغية. ولتحقيق هدف هذا البحث، ابتكرنا جميع العلاقات الفراغية الممكنة، التي تؤثر على تلك الجودة، كمدخلات لفراغات معمارية محددة باستخدام مجموعة من القواعد الوصفية. قمنا بتعريف نظام المنطق الرقمي الضبابي لفراغات معمارية سكنية والتي تم دمجها في تشكيل فراغي لتقييم التشكيلات الفراغية. ولهذا قمنا بتعريف كل المدخلات المتغيرة والمخرجات المتغيرة والقواعد الرقمية الضبابية ونقدم العلاقات بين الفراغ والفراغ باستخدام وظائف العضوية. تقترح الورقة إطارًا قائمًا على نهج المنطق الرقمي الضبابي للتقييم الآلي للتشكيلات الفراغية المعمارية.

يعتمد هذا البحث للوصول الي هذ الإطار على تحليل استكشافي باستخدام نهج استقرائي. لتحقيق ذلك أولاً، استعرض البحث أدوات تقييم التصميم الحالية - DQI، DEEP، AEDET، BREEAM، LEED، BQA، لتتمكن من استكشاف العوامل المختلفة التي تؤثر على تخطيط الفضاء. ثانياً: استخراج المدخلات المكانية على أساس المعايير المعمارية. علاوة على ذلك، تحديد النواتج المكانية بناءً على أدوات تقييم تصميم مماثلة. وبالتالي، يمكننا تحديد مجموعات القواعد التي تحدد العلاقة بين المدخلات والمخرجات. وبالتالي، يمكننا اقتراح إطار كامل يعتمد على نهج مبني على المنطق الغامض يتكون من المدخلات والمخرجات والقواعد التي تحدد العلاقة بينها، حتى نتمكن من تقييم التصميم.