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Using fuzzy inference system for architectural space analysis

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ABSTRACT

Though architectural space is the main source and the only indispensable component of any architectural construction, in many cases its boundaries are uncertain, leading intuitive spatial design. Creating a mathematical model of architectural space with concrete results will offer many possibilities for design process in analysing spatial organization, independently from in architect's experience and intuitions. This paper presents a fuzzy inference system based spatial analysis model for spatial analysis for architectural design which brings many advantages to design process. The aim of this article is to investigate the potential of a fuzzy system with a Mamdani inference engine, considering different numbers of membership functions. Two venues have been selected and the fuzzy inference system based spatial analysis model is applied. For better judgement, outcomes of the model have been compared to depthmap analysis model. The results of the model indicate that fuzzy inference system based spatial analysis model performs very well, even with the limited and imprecise data. Such prototype can evolve into a tool for identifying spatial formations for improvements during the architectural design process.

1. Introduction

The concept of architectural space, which the architecture profession is based on, is the main source and the only indispensable component of any architectural structure. However, this most indispensable component is not limited with certain boundaries most of the time. On the contrary, it is usually impossible to say where an architectural space exactly starts or ends. Architectural spaces are usually connected with each other by soft outlines. A part of an architectural space may be a part of another architectural space at the same time [1,2]. Especially in architectural constructions where many of such spaces are to be designed, an architect behaves intuitively depending on his professional knowledge and experience. In most cases it is possible to see whether the space is as desired or not, only after the construction is finished. While an architect with enough knowledge and experience will be able to design the space with desired properties, an inexperienced architect with less professional knowledge will not succeed in designing the space with desired properties and the results will mostly be irrecoverable.

The reason for creating a mathematical model of the architectural space is of particular significance in that such a model will offer many possibilities in analysing whether the design has enough components to form the desired spatial organization or not. Thus it will be possible to analyse and model an architectural space with uncertain boundaries independently from an architect's experience and intuitions. Through this model, any designed space can be cross-checked by its spatial properties and modified to provide the desired spatial organization prior to its construction.

Thanks to the architectural Computer Aided Design (CAD) technologies which have become a standart in architectural design process within the last decades, it is possible to visualize any architectural design before it has been constructed. However the results of these systems are not three-dimensional and in their original scales or most importantly in some cases they can rather be misleading than being supportive in the evaluation process [3,5]. In addition to the misleading results like deformed perspectives, most of the time the evaluation process can only be based on visual sense. Space syntax [6–9] and its main tools, axial map [6,7] and depthmap [10–13], are the most common tools used for architectural space analysis today [14]. Yet as it will be explained in further sections, spatial perception is a multi-sensored process [15], results of those systems are not totaly satisfactory enough for spatial analysis.

One of the mathematical models to compute uncertainties is fuzzy logic [16]. Fuzzy logic and sets were first introduced by Zadeh in 1965 to represent and manipulate imprecise data. Fuzzy logic and fuzzy sets were first introduced by Zadeh as a generalization of conventional sets theory [18,19]. This approach has been an alternative to classical Boolean logic for problems where uncertainties in means of imprecision, vagueness, imperfect knowledge exist. In Zadeh's theory, objects of the sets are represented with their membership degrees to that set [17,20–23]. The membership degree of an object determines the state of its belonging to a set. In fuzzy logic, elements of the sets are expressed by membership degrees.

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When x is a defined element of the fuzzy variable space X and $\mu_A(x)$, membership degree of this element to a fuzzy set A which is defined in this fuzzy variable space X, fuzzy set A will be expressed as

$$A : \{(x, \mu_A(x));\ \ x \in X\}. \tag{1}$$

The membership degree $\mu_A(x)$ takes a positive value between 0 and 1 for every element of the fuzzy set A [27,28]. Fuzzy set A is defined by the μ_x membership function which shows the membership degree of the set's elements expressed by x. Membership functions show one element's interest in one fuzzy set. The most important advantage of the fuzzy sets is the possibility of defining blurry limits between different sets, which means that an object may belong to different sets with different degrees of membership. Because of architectural spaces' uncertain and fuzzy characteristics making a mathematical model and analysis of it will be possible by fuzzy sets and fuzzy logic [24–26]. Although today the usage of fuzzy logic and fuzzy sets are very limited and relatively new in architecture, it will provide great advantages on spatial modeling and analysis in design process.

The aim of this article is to investigate the potential of a fuzzy system with a Mamdami inference engine, considering different numbers of membership functions. The paper is organized as follows. First, well known spatial analysis models in literature are explained shortly. Definitions of architectural space, spatial perception and characteristics of the spatial elements are briefly explained in Section 3. In Section 4, general information about the applied model is explained. The fuzzy inference system based spatial analysis model is applied on two selected venues in Section 5. For better judgement, outcomes of the model have been compared to the results of the depthmap tool which is commonly used in space syntax to analyse physical properties of architectural venues. Finally, advantages of the proposed spatial analysis model will be discussed.

2. The subject of spatial analysis and well known models

In this section, the subject of spatial analysis and the well known models are explained.

2.1. Spatial analysis, space syntax and axial map

Originally the term of space syntax was conceived by Bill Hillier, Julien Hanson and colleagues at University College London in late 1970s as a tool to help architects simulate the likely social effects of their design [7]. The main idea of space syntax was to divide the spaces into components and analyse to represent with graphs and maps, called axial map, that describe the relative connectivity and integration of those spaces. By the help of these maps and graphs a designer will have the opportunity to analyse any space by the means of social relations and properties. After this tool other concepts are also developed to analyse a space by its different properties.

2.2. The concepts of isovist and visibility graph analysis

In addition to the social properties of a space visual properties also effect the spatial perception strongly. For analyzing a space by its visual properties the concept of isovist was developed and popularized by Michael Benedikt at University of Texas [11].

An isovist is basicly the polygon of the field of view from any particular point (Fig. 1). Isovists are naturally three-dimensional, but they may also be studied in two dimensions: either in plan or in vertical sections through the three-dimensional isovist. Every point in physical space has an isovist associated with it [11].

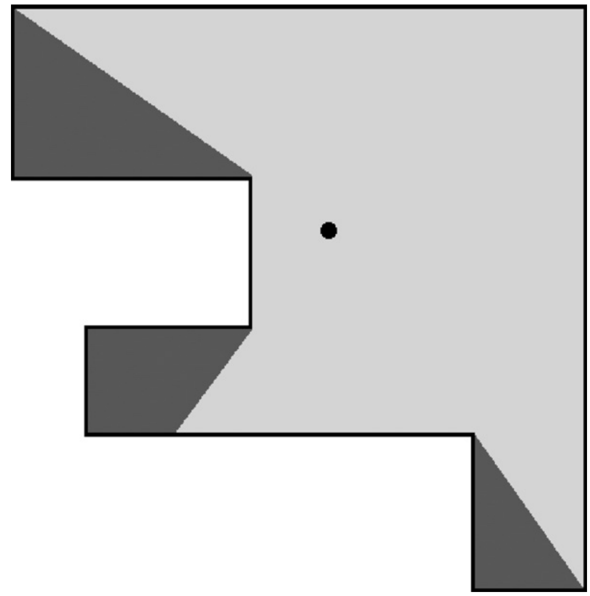

Fig. 1. An isovist from a point where lighter grey areas define the visible parts and the darker areas define invisible areas.

The boundary-shape of an isovist may or may not vary with location in, say, a room. If the room is convex, like a rectangle or circle, then the boundary-shape of every isovist in that room is the same. But if the room were non-convex, like an L-shaped room, or a rectangular room with partitions, then there would be many isovists whose area would be less than the whole room's. One can also think of the isovist as the volume of space illuminated by a point source of light.

The visibility graph analysis applications were first introduced by Braaksma and Cook [65,12]. Braaksma and Cook calculate the co-visibility of various units to produce an adjacency matrix to represent these relationships, placing a 1 in the matrix where two locations are mutually visible, and a 0 where they are not. From this matrix they propose a metric to compare the number of existing visibility relationships with the number which could possibly exist, in order to quantify how usefully a plan satisfies a

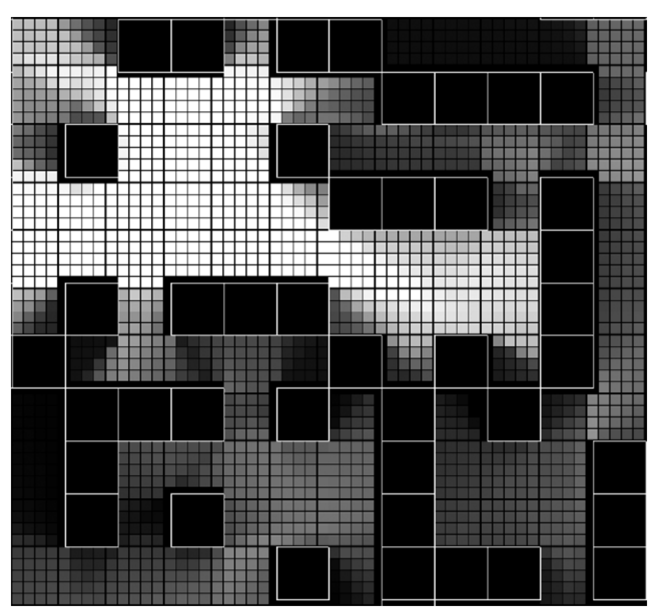

Fig. 2. A sample layout calculation with the depthmap tool [12].