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USING ARTIFICIAL NEURAL NETWORKS AND SPACE SYNTAX TECHNIQUES TO UNDERSTAND MASS HOUSING DESIGN PARAMETERS

VELİ MUSTAFA YÖNDER
Faculty of Architecture, Izmir Institute of Technology, Izmir, Turkey, veliyonder@iyte.edu.tr

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Abstract

The design of mass housing is a complex process that involves the use of a large number of components and parameters. The field of design has unavoidably been changed by the impact of digitalization, which has resulted in the proliferation of computational design models, data structures, artificial intelligence, and an algorithmic way of thinking. Artificial neural networks, space syntax methodologies, predefined rules will help shape the steps of the schematic design process and establish certain limitations. Within the confines of this research, predefined guidelines were used to bring about geometric variances in the design of mass houses. Both traditional and digital instruments were utilized in the process. Methodologies based on artificial neural network models and space syntax techniques were utilized to investigate case studies and develop prototypes. The artificial neural network model is designed to understand the factors affecting mass housing design parameters. The importance percentages of the parameters were determined according to the outputs of this model. Besides, methodologies based on space syntax have had a significant impact, both on decision-making processes and on feedback-based design. In this study, several digital tools were used to analyze such as visibility graph analyzes, node-based techniques, and isovist analysis. In the section devoted to the conclusion, the comparison of the various prototypes that were obtained, the findings of the space syntax analysis, and the various stages of model development are discussed.

Keywords

Architectural Configuration, Artificial Neural Networks, Rule-based Design, Visibility Graph Analysis (VGA), Isovist Analysis

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The design of mass housing is a complex process that involves the use of a large number of components and parameters. The field of design has unavoidably been changed by the impact of digitalization, which has resulted in the proliferation of computational design models, data structures, artificial intelligence, and an algorithmic way of thinking. Artificial neural networks, space syntax methodologies, predefined rules will help shape the steps of the schematic design process and establish certain limitations. Within the confines of this research, predefined guidelines were used to bring about geometric variances in the design of mass houses. Both traditional and digital instruments were utilized in the process. Methodologies based on artificial neural network models and space syntax techniques were utilized to investigate case studies and develop prototypes. The artificial neural network model is designed to understand the factors affecting mass housing design parameters. The importance percentages of the parameters were determined according to the outputs of this model. Besides, methodologies based on space syntax have had a significant impact, both on decision-making processes and on feedback-based design. In this study, several digital tools were used to analyze such as visibility graph analyzes, node-based techniques, and isovist analysis. In the section devoted to the conclusion, the comparison of the various prototypes that were obtained, the findings of the space syntax analysis, and the various stages of model development are discussed.

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ملخص

يعد تصميم مشاريع الإسكان الكبرى عملية معقدة تتضمن استخدام عدد كبير من المكونات والمتغيرات. وقد تغير مجال التصميم حتما بسبب تأثير الرقمنة، مما أدى إلى انتشار نماذج التصميم الحوسبية، وهياكل البيانات، والذكاء الصناعى، وطرق التفكير الحوسبية. وتعتبر الشبكات العصبية الصناعية ومنهجيات بناء الفراغ والقواعد المحددة مسبقا من التقنيات التى ستساعد على تشكيل خطوات عملية التصميم المبدئى وإرساء بعض المحددات. وفى هذا البحث، تم استخدام إرشادات محددة مسبقا لإنشاء نماذج هندسية عديدة ومتباينة فى إطار عملية تصميم مشاريع الإسكان الكبرى، وذلك باستخدام أدوات تقليدية ورقمية. وقد تم استخدام منهجيات مبنية على الشبكات العصبية الصناعية ومنهجيات بناء الفراغ للتحقيق فى دراسات حالة وتطوير نماذج أولية. فقد تم تصميم نموذج شبكة عصبية صناعية بهدف فهم العوامل المؤثرة على المعايير والمتغيرات الخاصة بتصميم مشاريع الإسكان الكبرى. وتم تحديد النسب الهامة المتعلقة بتلك المعايير بناء على مخرجات النموذج. وقد كان لمنهجيات بناء الفراغ تأثير كبير على كل من عمليات صنع القرار والتصميم المبنى على التغذية المرتجعة. وفى هذه الدراسة، تم استخدام العديد من البرامج الرقمية التحليلية مثل تحليلات الرسم البيانى للرؤية والتقنيات المبنية على نقاط الالتقاء وتحليل برنامج الأيزوفست. وتخلص الورقة البحثية إلى استعراض لمقارنة بين كافة النماذج المطورة التى تم الحصول عليها بالإضافة إلى نتائج تحليلات منهجيات بناء الفراغ وكافة مراحل تطوير النماذج.

الكلمات المفتاحية: التكوين المعمارى، الشبكات العصبية الصناعية، التصميم المبنى على القواعد، تحليلات الرسم البيانى للرؤية، تحليل برنامج الأيزوفست.

1. INTRODUCTION

As the impact of digitalization and emerging form-finding tools increases, the roles and responsibilities of the modern designer are changing and transforming into new forms. Specifically, novel ways are used to develop and support design stages that transition from conventional to digital creative processes. Within this framework, the effect that the designer has throughout the process is rethought and explored in relation to the shifting conditions. The stages of the design action, which are expected to include creative thinking (Casakin et al., 2010) and iterative stages (Burry, 2004) by their nature, include the steps of developing and concretizing the original ideas proposed for the solution of the defined design problem. Artificial intelligence (AI) approaches, unique protocols, digital tools, and hybrid models (which combine digital and analog methods) are all viable options developing novel and innovative concepts in mass housing design. Furthermore, traditional approaches such as sketching, physical modeling, and diagramming may be used to construct a strategy that is based on potential outcomes and can be utilized in developing a representation for the initial design idea. According to Oxman (2006), the active involvement of the computer in solving the design problem is different from simply making digital drawings when considering the computational design stages. The emergence of computer-aided design (CAD) and building information modeling (BIM) technologies due to the impact of digitalization has resulted in creating new opportunities for designers. These opportunities may be summarized as follows: Computer-aided design technologies have the potential to make a constructive contribution to the stages of the design process that include creative problem solving, early design phase, communication, and visualization (Robertson and Radcliffe, 2009). Besides, with the introduction of creative digital tools and advanced computational models, there is a greater demand to comprehend and control the design process.

Artificial intelligence approaches include efficient models for solving complex and non-linear problems. Artificial neural networks (ANNs), which are components of supervised machine learning approaches that mimic the brain (consisting of neurons), enable meaningful interpretations and inferences from the processed data. According to Tayfur (2020, p.4) “ANN is inspired from the information processing of biological nervous system, such as the brain”. The human brain, however, works entirely differently from a traditional digital computer and has always fueled the interest in studies of neural networks or somewhat artificial neural networks (Haykin, 1996). These models, by their nature, are very effective in revealing relationships and tacit knowledge that seem complex in terms of the number of inputs and advanced algorithms. Human intelligence is based on a serial system and deals with a complex data only through interpretive mechanisms. In contrast, AI, benefiting from parallel processing, could handle complex and large amounts of data. Computational learning algorithms and AI-based approaches, which have a sophisticated framework, make eloquent extrapolations by utilizing forecasting models and learning types (i.e., supervised learning, reinforcement learning, hybrid learning, unsupervised learning, etc.), and statistical analyzes of enriched data in various dimensions. These approaches can fulfill essential components of reasoning modules and learning types. The effects of these machine learning models are increasing not only in engineering but also on the designer’s tasks and design methods. Estimating the parameters and importance percentages that affect the design processes can be tested with machine learning approaches. Within the scope of this study, the parameters affecting the mass housing design were tried to be estimated according to the artificial intelligence model. As a result of the development of the multi-layer perceptron model, also known as MLP, it is now much simpler to conduct an analysis of many design parameters' variables, which in turn grants the designer increased control over the process. Combinations are constructed by adhering to a set of criteria and presumptions that are specific (based on equations). The rules that influence the design of mass housing were attempted to be determined as part of the scope of this study, after which alternative housing designs were developed based on these rules. Several aspects, including spatial connections and arrangements, decisions made by the designer, geometric manipulations, and the overall architectural program, are taken into consideration. After that, space syntax approaches were used to conduct an analysis of the variances. Developed models were then reexamined based on the criteria that were used to choose the models.

2. LITERATURE REVIEW

The project inputs can influence the decisions and changes that are made during the process from the concept design stage to the final product creation. An in-depth knowledge of these inputs can be gained through using artificial neural network models, learning algorithms, mathematical equations, parameters, and computational models. The role of the computational approach, parametric/algorithmic stages, and the effect of digital design tools are enhancing day by day, and its scope is expanding (Caetano et al., 2020). Furthermore, design activity can benefit from computational strategies when viewed as a paradigm for guiding design research (Liddament, 1999). According to Kotnik (2010, p.11), computability and its importance for digital design in architecture illustrate that “the computer is not a neutral” instrument, but actively shapes how designers approach design. Numerous academic works have been dedicated to the study of mathematical methods (e.g., descriptive geometry, geometric algebra, associative geometry, Boolean operations in CAD, etc.) for elucidating design difficulties and formulating methods for resolving them (Pottmann et al., 2015; March 1976).

The effective use of parametric modeling tools can affect the design stages in many ways (Abdelmohsen and Do 2009; Qian et al. 2007). By combining digital computation with analytical design processes, the parametric design provides architects and designers with new ways to explore, simulate, and analyze multi-dimensional forms (Tang, 2014). According to Kolarevic (2013, p.52), parametric design is a digital technique that enables endless variety of shapes and forms, either through the drawing and modeling software's “embedded geometry” or by “visual programming tools” or “scripting”. On the other hand, algorithms that seek repetitive patterns, universal principles, changeable modules, and inductive relationships can improve human intellect by extracting new knowledge (Terzidis, 2006). Approaches such as computational, parametric, algorithmic, and generative (Nagy et al., 2017) methods all begin with defining the rule set (except for machine learning models and generative adversarial neural networks). For instance, the parametric design approach entails activities such as defining parameters, formulating equations, establishing connections (predecessors and successors), and making use of logical operators.

Artificial intelligence (AI) and machine learning have advanced significantly over the past couple of decades and now include a wide range of powerful tools that can be implemented thanks to the proliferation of low-cost computers, massive datasets, and the Internet (Nilsson, 2010). The field of machine learning, which includes concepts of "artificial intelligence, probability and statistics, computational complexity, information theory, psychology and neurobiology, control theory, and philosophy" (Mitchell 1997, p.17), is rapidly expanding in assorted disciplines. Neural network architectures trained with supervised or unsupervised methods are exploited in "aircraft control, credit card fraud detection, vending machine currency recognition, and data mining" (Nilsson 2010, p.509). Since the human brain can be thought of as a type of machine, there is no obvious boundary between the fields of AI (the study of making robots do tasks traditionally associated with human intellect) and psychology (Minsky, 1988). Compared to human intelligence, AI has the capacity to process large amount of complex data quickly and efficiently, hence, the current interest in neural networks and machine learning. The artificial intelligence ecosystem has seen different phases of development during the last century and has made significant progress and gained momentum in the previous ten years. Research in artificial intelligence started only in the 1950s after modern computers were invented, and it inspired a flood of ideas about how machines could do things that only minds could before (Minsky, 1988). Computer scientist Tom Mitchell (1997) divided the researchers working on the neural networks into two groups: The objective of employing ANNs to explore and mimic biological learning processes has inspired one group, and the rest of them has driven by the desire to develop highly effective machine learning algorithms, regardless of whether they mimic biological processes. Artificial neural networks are employed in the implementation areas of various disciplines such as archaeology (Pawlowicz & Downum, 2021), computer graphics (He et al., 2016), computational design (Chaillou, 2020), medicine (Frid-Adar et al., 2018), engineering (Tayfur & Singh, 2006), and architecture (Nauata et al., 2020).

Another computational model approach, space syntax (Jiang, 1998), is included in the analysis part of this study. The term "space syntax" refers to a range of approaches that can be used to represent and analyze various types of spatial layouts (Hillier, 1999). The analysis of spatial configurations has been the primary application of the mathematical framework known as “space syntax”, which is founded on topology and graph theory (Jeong and Ban, 2011). In the study of Schaffranek and Vasku (2013, p. 2), they present "different approaches to using Space Syntax as a constraint in the computational design process." Recent works on space syntax try to “simulate spatial design proposals” and figure out how they would work by coming up with consistent ways to represent and analyze spatial patterns (Dursun 2007, p.4). Methodologies of space syntax, which are useful approaches in the fields of architecture and urban planning, it helps to obtain analyses such as the relationship between places and the interaction of users. The designer will also find great value in conducting research into the connections that exist between different areas. Consequently, it can be described as an efficient criterion for identifying design variations.

3. METHODOLOGY

Data collection, defining rules, building an artificial neural network (ANN) model, variation extraction, and spatial analysis make up the major components of the methodology utilized in this study. During the data collection phase, satellite images, sample projects, land boundaries (in the form of drawing files and 3d models), and project inputs were collected. During the formulation of the rules, the factors that impacted on the architectural program were considered. User types, social areas, areas with greenery, circulation areas, semi-open areas, closed areas, and open areas are some of the elements that are examined (Figure 1). A rule-based approach was used to design a mass housing project that included seventy-five flats and social facilities as part of the scope of this study. Iterative execution was used for all these processes. A process of iteration occurred between the act of sketching and the act of modeling. During the concept design phase, both digital and analog drawings were used to develop the project's initial models. Then, site plans were created based on parameters including area calculations, solid-void relationships, flat types, and project inputs (according to the results of the ANN model). An artificial neural network model was developed with the JustNN (Neural Planner Software, version 4.0b). All input and output values are standardized between [0,1]. The design iterations that were generated as a result were evaluated using space syntax tools. Assorted digital tools were employed in this study. “Harmony” project (Accessed 13 March 2021) was used to gain digital sketches. Furthermore, Autodesk AutoCAD® 2022 and Revit® 2022 were used to model (e.g., components and parametric objects) and modify geometries (e.g., surfaces, polygons, etc.). DepthmapX (Varoudis, 2012) was used to obtain visibility graph analysis (VGA). Visibility graphs for both site plans (Kumar, 2019) and architectural floor plans were examined. Besides, Syntax2D (S2D) (Wineman et al., 2007) tool was used to obtain isovist analysis. AGraph (Manum et al., 2005) was used to get node-based graphs and internal distances, mean depth, relative asymmetry, difference factor, and integration values.

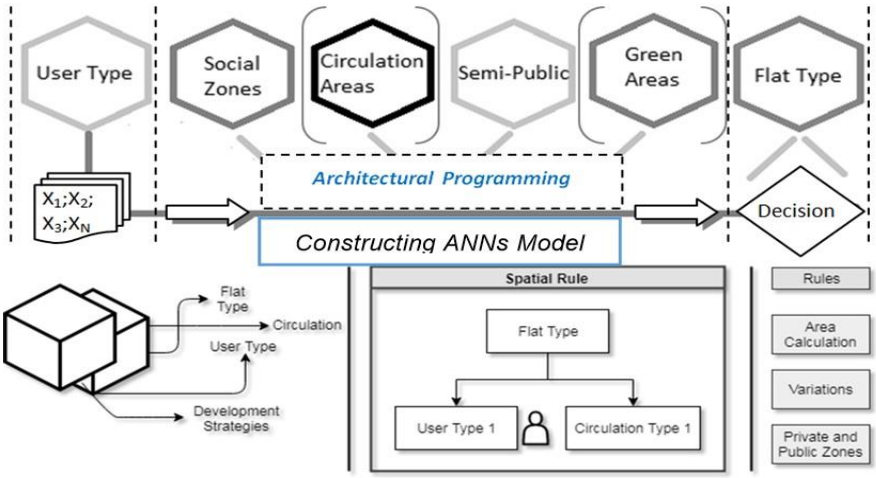

Fig.1: Architectural programming and primary rules for mass housing development

3.1. Analysis of Spatial Relations of Housing Units

Space syntax approaches can be used to understand the structure of houses and evaluate their spatial relationships (Hanson, 2003). Numerous strategies have been developed in space syntax approaches that utilize schematic representations to facilitate the identification of spatial variations and system components. Consequently, these strategies were based on the designs of the individual units that make up the mass housing structures, as well as the rules governing how they are assembled (e.g., shape grammars, cellular automata, rule-based approaches, parametric protocols, etc.). Initially, it is necessary to ascertain the areas (2d) and volumes (3d) that the architectural program requires. Justified graphs, which are tree-like structures, are used as part of the concept of space syntax (Orhun et al., 1995; Klarqvist, 2015). Besides, the integration of contemporary housing projects from an architectural firm with the spaces has been analyzed (Figure 2). Later, it was interpreted with the rule-based approach, and many alternatives were developed (Figure 2).

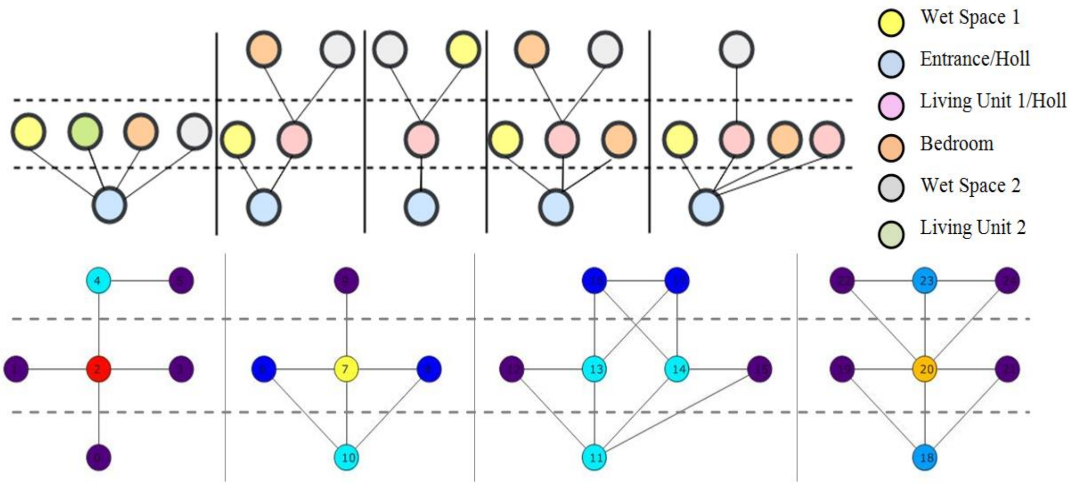

Fig.2: Accessibility graphs of examples of modern mass housing components (by functions) (upper) and suggested variations

Sample projects were examined and evaluated via space syntax digital tools (Figure 2 and 3). In this context, isovist analysis (occlusion, compactness, and area) was implemented at various points on the sample layouts (Figure 3).

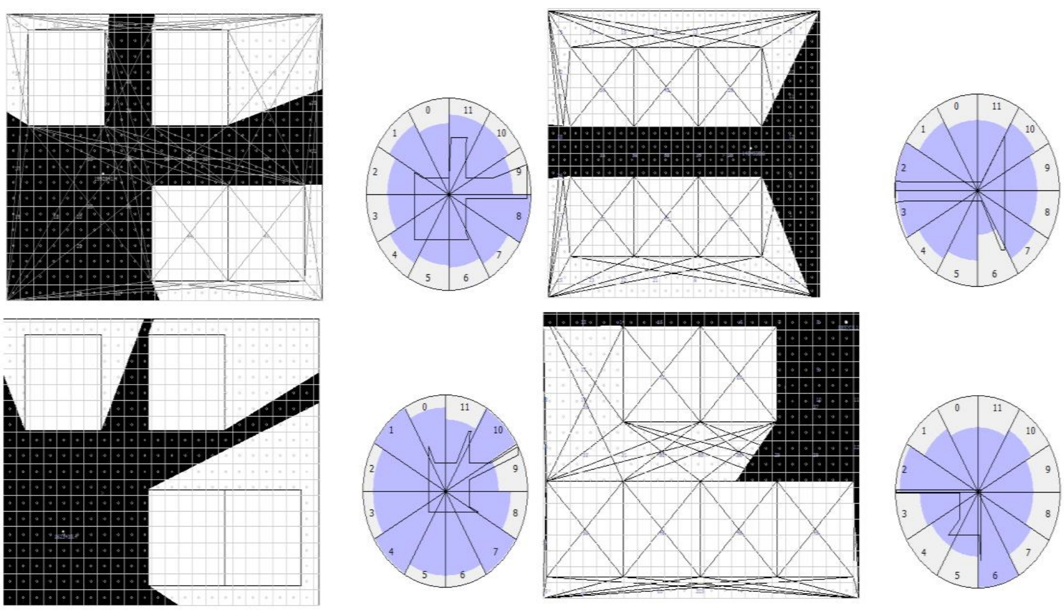

Fig.3: Point isovist analysis of the case studies' layouts

3.2. Constructing Artificial Neural Network (ANN) Model

According to Zadeh (1996), the pioneer of fuzzy logic, all approaches such as neural network theory, probabilistic reasoning, fuzzy logic, evolutionary computing, and chaotic systems could all be grouped under the umbrella of soft computing. One of the soft computing systems, these networks try to replicate the rudimentary tasks of neurons, axons, soma, dendrites, and synapses in the human nervous system in a digital environment. Due of the sophistication of nerve cell structure, even supercomputers are inadequate; hence, basic neural models have been constructed (Baykal and Beyan, 2004). Neural networks, whose usage areas have diversified with the enrichment of data and the development of reference models over time, basically consist of input, output, and hidden layers. According to Tayfur (2020, p.14) “An artificial neuron is a model whose components have direct analogies to components of a biological neuron". The multilayer perceptron (MLP) has been applied to predict future trends, approximate relationships between variables, and classify data into discrete classes (Gardner and Dorling, 1998). Activation function (e.g., ReLu, log-sigmoid, ELU, TanH, etc.), number of neurons, optimization algorithm, learning rate, learning momentum, and epoch number are some of the hyperparameters for training ANN models. Within the scope of this study, the artificial neural network model was developed based on sample projects’ gross area, net area, number of rooms, number of bathrooms, whether there is a balcony, whether there is a vista, and preference score (in correlation with price) parameters (Figure 4). In final neural net, the gross area is not included in the model.

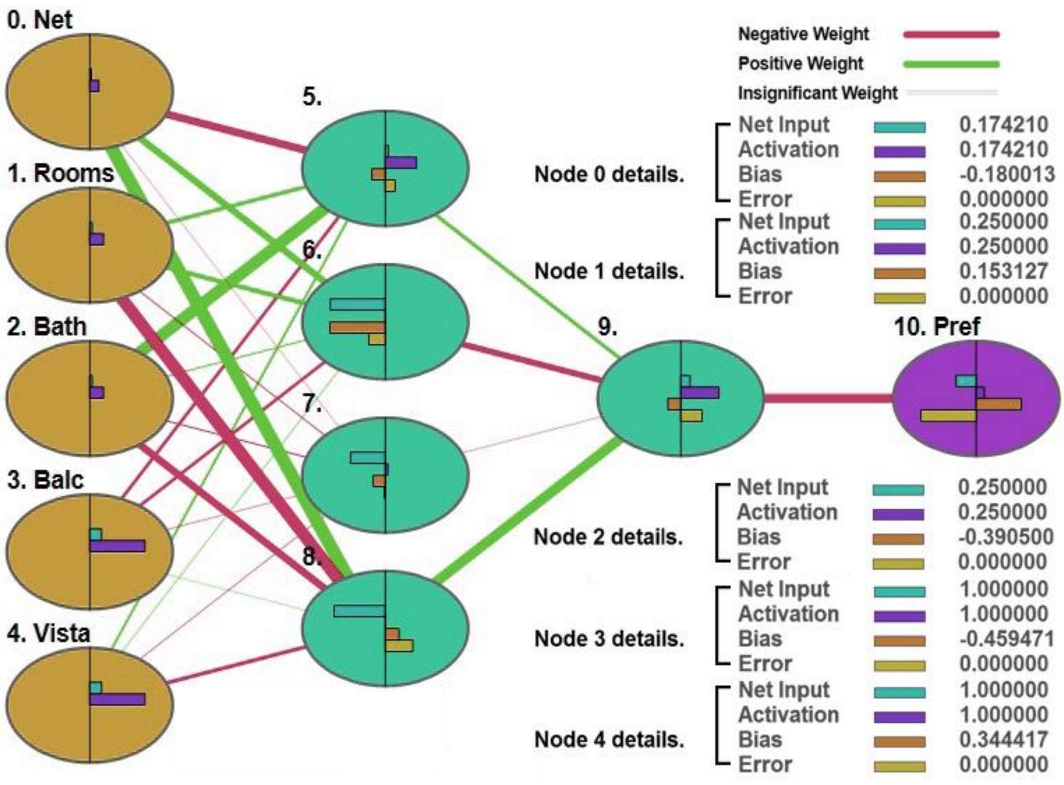

Fig.4: Development of the artificial neural network model

The artificial neural network model was developed with a feedforward and back-propagation learning algorithm. Only twenty-four instances were used for training, while the remainder were utilized for validation. During the training phase, the learning cycle value was 18301, the mean error was 0.051%, the target error was 1%, the validation accuracy was 100%, the learning rate was 0.6, and the momentum was 0.8 (Figure 5). The relative importance of the input factors is as follows: net area, number of rooms, number of bathrooms, presence of a view, and presence of a balcony. (Figure 5).

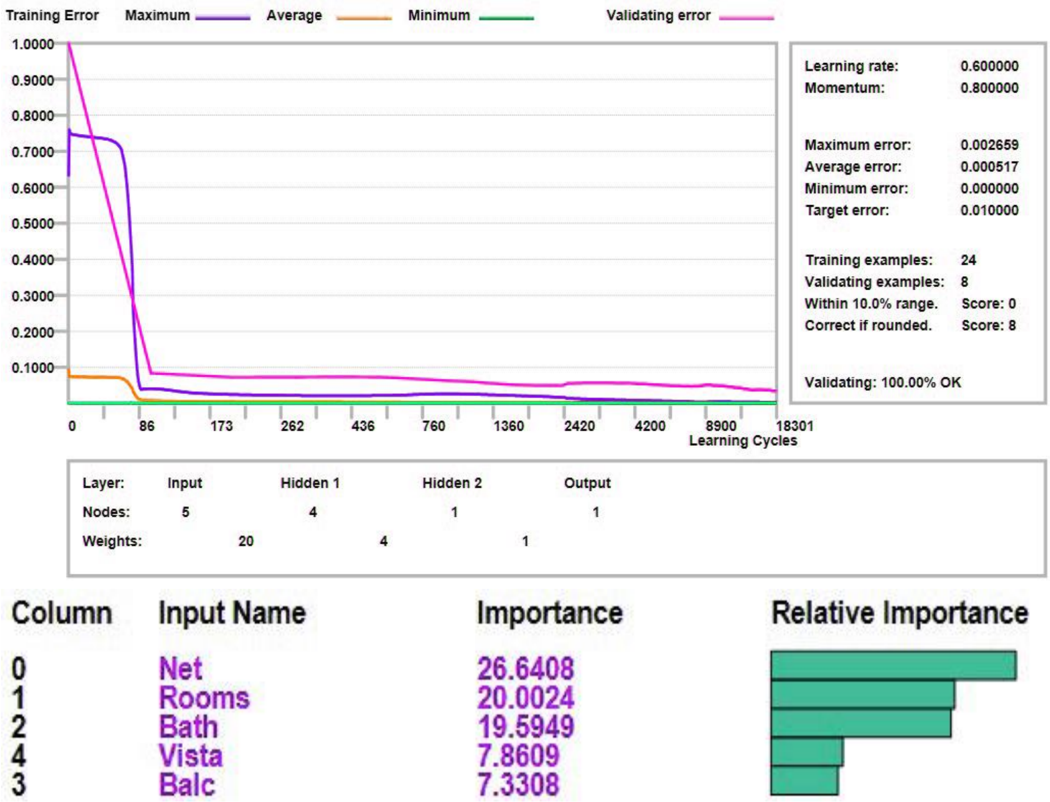

Fig.5: Network learning progress plot (upper) and inputs' relative importance chart

4. RESULTS

The first result of this study is the development of concepts that were developed with digital and analog procedures for the initial part design stages. The rules that must be followed during the development process have been established, including the outputs of the ANN model, the architectural program, design decisions, space syntax approaches, and geometric characteristics. The investigation into the appropriate distribution of mass resulted in producing eight prototypes, six of which had solutions in two dimensions, while the remaining two contained solutions in three dimensions (Figure 6). According to the factors affecting the housing design (ANN model outputs were also taken as reference), design alternatives were produced iteratively with parametric CAD and BIM tools. Throughout this development process, many parameters, such as solid-void ratios, outputs from neural network models, and space syntax methodologies, were utilized.

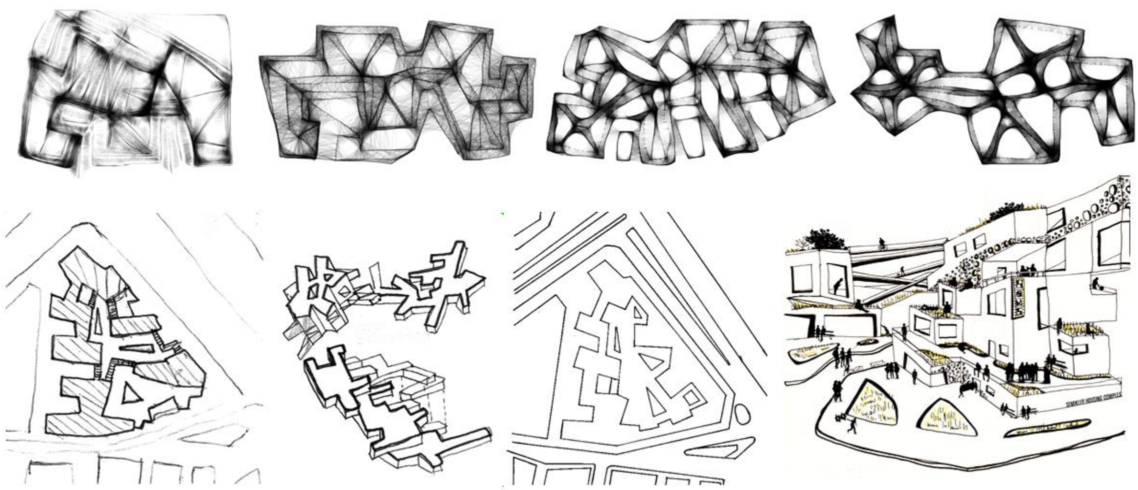

Fig.6: Schematic design phases with digital sketches (upper) and hand drawings

The process of iteratively modifying and fine-tuning mass geometries is an essential component of producing design alternatives. At this stage, another important concern is incorporating the social space design (e.g., open, and semi-open space configurations) into the overall structure. During the first stage of design development, a total of twelve different settlement types and masses were created (Figure 7).

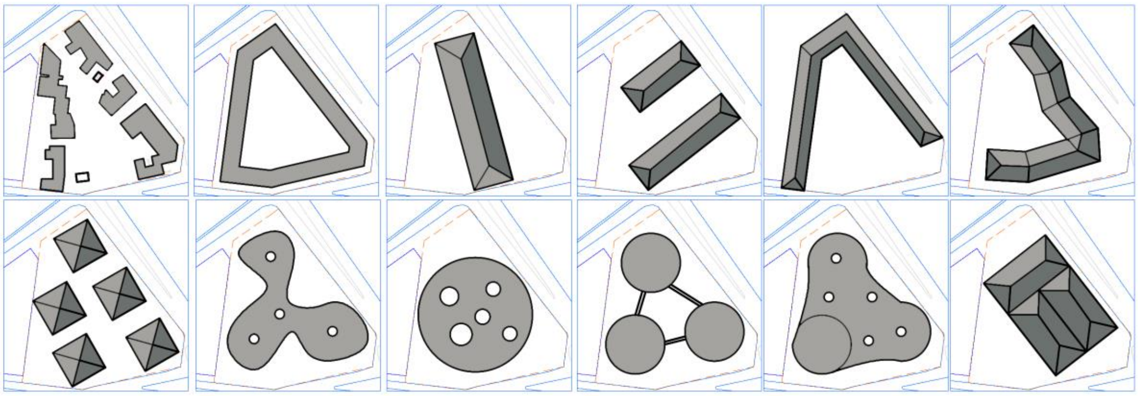

Fig.7: Mass modelling stages and design variations with parametric CAD tool

Nevertheless, according to the ANN model's input relative importance, just four of them were chosen, and the development phases was carried on from there. As a result of this, four dissimilar strategies have been investigated to lessen the density of the masses. The design decisions for floor plans and site plans incorporate all four of the previously mentioned alternative approaches. Simultaneously, visibility graph analyses (VGA) were obtained (Figure 8). In some blocks, the correlation between the number of rooms (input parameter of the ANN model) and the kind of dwelling stays the same, but in other blocks, it veers off in a different direction. Besides, the organic plan scheme features block that have a geometry that combines multiple surfaces into polygons. The purpose of its multiple surfaces is to broaden the viewing area as well as facilitate the participation of a greater number of people in visual communication.

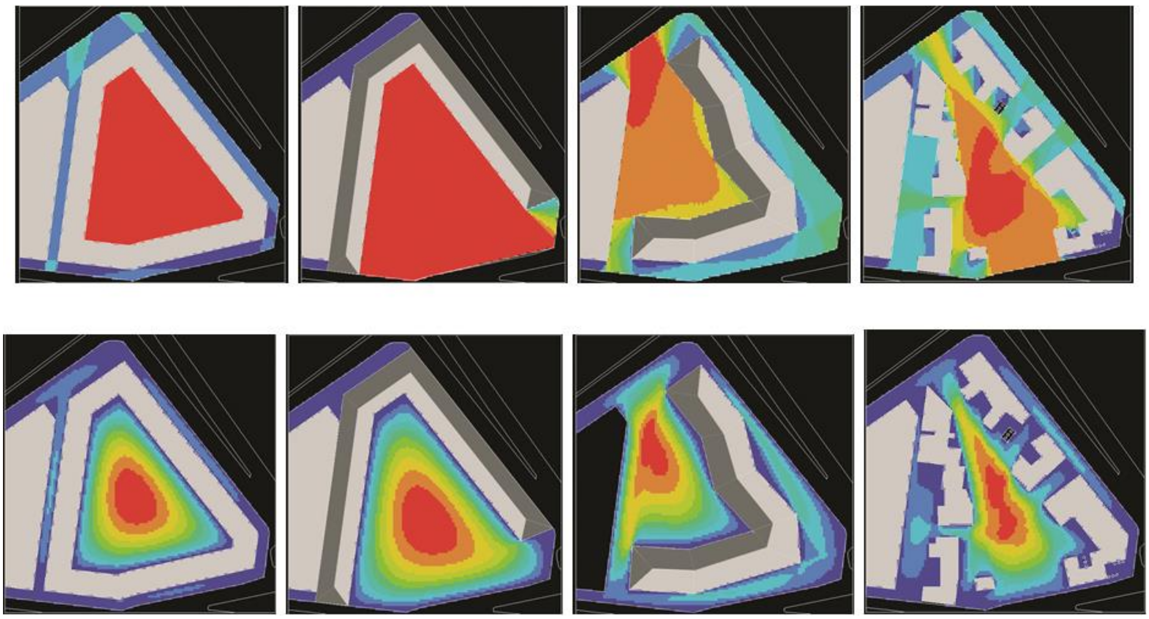

Fig.8: Results of visibility graph analysis (VGA)

Four dissimilar design possibilities were generated using technology from parametric computer aided design approach and building information modeling (BIM) (Figure 9). Since there are several phases of concept design, an attempt was made to improve the solid-geometry-based requirements that were generated. The level of detail in the variants was carefully maintained.

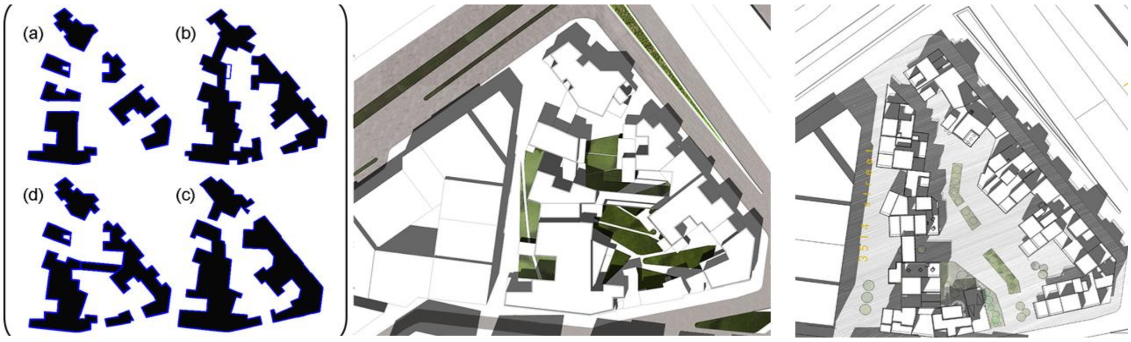

Fig.9: Schematic design variations via parametric CAD tool (left) and BIM tool

Boolean operations such as subtraction, union, and intersection (Sun et al., 2001) and geometric calculations are included in the modification and manipulation steps. Regarding the design of floor plans (Figure 10), the application of space syntax methodologies has proven to be extremely helpful.

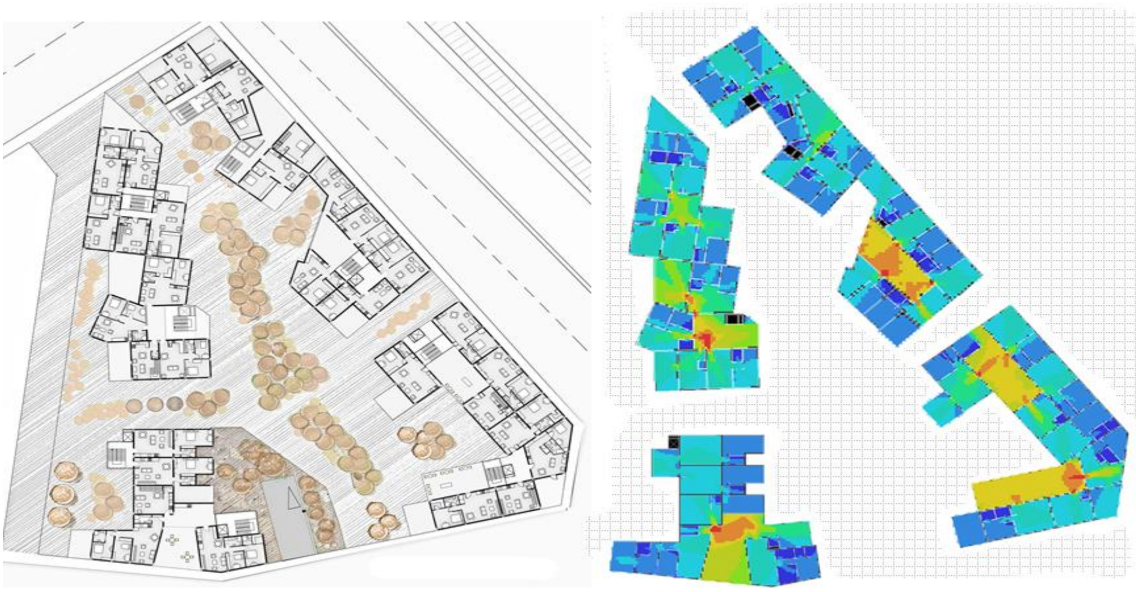

Fig.10: Producing floor plans (left) and results of VGA

As a result, it has made it possible to conduct metric analyses on the differences between the various design alternatives. Analyses were done on the potential routes and visibility of users, with an emphasis on connectivity (Figure 10). Following the completion of the mentioned computations, an attempt was made to reconstruct the proposed connection between the defined areas. In this regard, some flats do not share an entryway with neighboring flats (because some apartment types are two-storey, some are three-storey). In addition, when planning the layout of the communal spaces, their volume was considered. Furthermore, it is necessary to conduct a three-dimensional analysis due to irregular polygonal geometry, architectural programming, and multi-surface scenarios. This was done because it was essential to determine whether the buildings would have one or two levels. The mass formation benefits enormously from undergoing development stages as well as trials that take place in three dimensions (Figure 11).

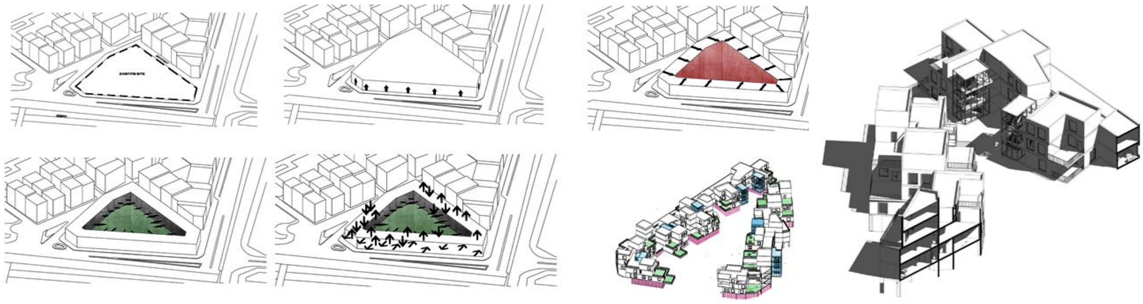

Fig.11: Modelling and modification phases of 3D geometries with BIM tool

5. DISCUSSION

Digitalization has an impact on decision-making and problem-solving strategies for complex situations, such as extracting and analyzing design patterns. As the stages of design thinking entail several dimensions and phases, the process of establishing or attempting to comprehend precise design principles is laborious. Benefits in terms of decision-making can be reaped by employing the rules and ANN models' designated parameters. The settings of the rules and parameters that constitute the basis of these models are different for every design challenge that might be posed. Artificial neural networks, a form of machine learning, are a potent method for resolving complex design issues. The importance of creative thinking aided by sketches, rule-based design approaches, artificial intelligence methodologies, and space syntax techniques cannot be overstated in the context of the schematic design steps. Thinking with a sketch, which is the foundation of the design concept, is one of the primary components of analytical thought in the study of ill-defined design challenges. Iterative processes, which are features of creative thought, also contribute immensely to design thinking in a positive way. The need of producing prototypes iteratively and incorporating input has become a major aspect in tackling complex design problems. The resulting alterations on the design are of such a kind that they adhere to the established guidelines. Besides, the designer can construct the specified associative geometry using digital tools. On the other hand, these tools do not compete with the designer's authority; it only supports him/her. An artificial neural network model was developed at the beginning of this research project to gain a better understanding of the parameters of the mass housing design strategies. The training of the multi-layer perceptron is very significant for the stages that involve decision making. In addition to this, the developed network was used in order to gain an understanding of the relative input importance of the parameters that were specified. On the other hand, space syntax approaches (i.e., visibility graph analysis, isovist analysis, and node-based spatial analysis) have been used to evaluate design alternatives. This study demonstrates the importance of bridging the ANN model, space syntax methodologies, parametric CAD and BIM tools, and 3D design development procedures for mass housing design protocols. In future research, various learning algorithms will be employed to estimate the design characteristics of mass housing.

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