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OUTPATIENT CLINIC DESIGN THROUGH RULE BASED DESIGN METHODS

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ABSTRACT

Health is one of the basic needs of humanity. People use hospitals to control and treat their health. As the most advanced health structures, hospitals have been transformed with new requirements and systems throughout history. Health structure design contains various inputs, data, and criteria. This study reveals the network of relations with a rule-based design method to provide systematic design assistance for architects. Hospitals have complex structures in terms of the design solution and production management. Therefore, it will be useful to systematize these complex structures for design inputs to create a base for the architectural program. Within the framework of this study, rule-based design approaches were adopted for hospital polyclinics. Polyclinics work independently but are linked to the main hospital system. Today the main design problems in polyclinics are accessibility and visibility. The main purpose of this study is to create a model base for alternative plan types by taking advantage of the productive method: rules-based design. Firstly, to consider the functional relations and distances among multiple units for an optimum solution, the study evaluates the existing working designs and their derivatives. Secondly, it addresses the optimization of hospital polyclinic design in terms of obtaining the minimum route overlap, minimum walking distance, and high visibility of the patients in the polyclinics. Thirdly, due to the repetitive nature of polyclinic spaces, the space grammar method has been used as a rule-based approach for the derivation of spaces. The genetic algorithm method used together with the shape grammar is included in the study to process the formal and numerical data and to compare the original design alternatives. The spatial sequence technique of Space Syntax is used as an evaluation method. In the mixed method of this study, the relational information obtained from existing hospitals has been resolved. These relations have created design rules for an outpatient polyclinic architectural program by binary and triplet relations. Alternative productions with the genetic algorithm tools have been generated through the Rhino / Grasshopper software extension. The generated plans have been evaluated with the spatial sequence technique of Space Syntax theory to explore optimum solutions for distance and visibility.

Keywords: Architectural design, Genetic algorithm, Space syntax, Outpatient clinic design, Shape grammar, Rule-based design

1. INTRODUCTION

Health is one of the basic needs of humanity and enables people to continue their lives unhindered. Health care is a right for everyone to maintain his/her life in international law and the constitutions of countries. Health rights are provided to patients through hospitals with health services. As important health structures, hospitals are like living organisms consisting of many health care compounds. Although many health institutions like health centers, local health centers family planning centers and laboratories exist in Turkey, hospitals are at the top of the most-used health institutions. They are included in the 'complex function' structure class with a variety of users and different functional groups within their structure [1]. As the most advanced health structures, hospitals have been transformed with new requirements and systems throughout history. As a result of the discussions and studies carried out in the second half of the 20th century, especially between the years 1950-1980, a wide literature on hospital designs were created and hospital structures developed as a result of technology, construction system, and inventions. The change and transformation experienced over the years have brought variations in the hospital design language.

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While language consists of a set of words with rules, architecture produces spaces that shape life with rules. Just as the language consists of a combination of canonical words, architectural designs may form space within the framework of certain rules (standards) according to function, environmental data, and topography. In order to analyze the design language of the resulting space, new spaces can be derived by analyzing the formal formation rules of the design language and producing meaningful rules with the shape grammar analysis technique. The aim of this study is to produce a rule-based model by using computational design methods to reveal the polyclinic plans of hospitals with complex functional structure types that have the same use as the shape grammar analysis technique and create shape rules and produce new plan types. The theoretical background of the study is based on the rule-based design approach. Hospital structures have a rule-based understanding in terms of both workflow, settlement and space relations. According to this work scheme, patient registers to nurse counter, waits for the polyclinic queue, examined in the proper section, the examination is directed if desired, and if not, the treatment method is given and the patient is released from the polyclinic (Figure 1).

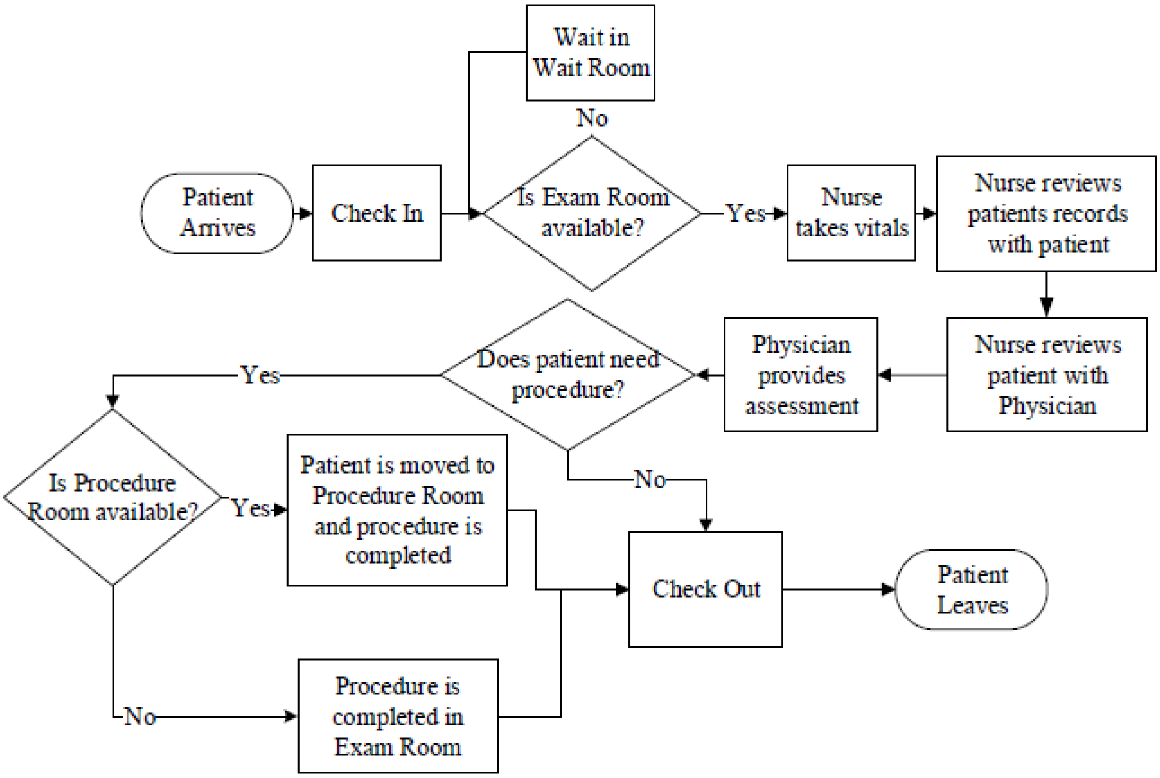
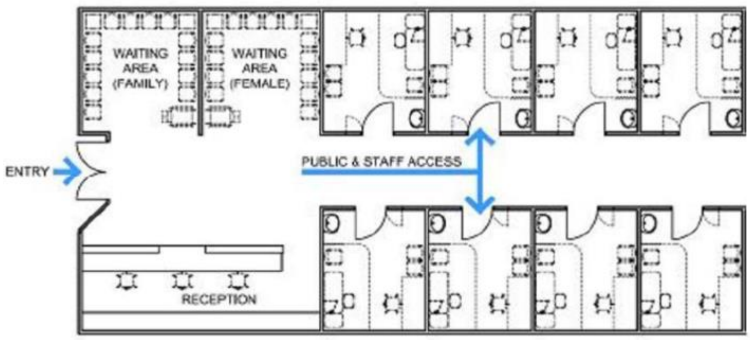


Figure 1. Hospital Polyclinic Work Flow Scheme [2]

The plan is a representation of a design in two dimensions; it can be defined as the numerical/linear expression of the practice. Hospital plan diagrams may have variety of single and double corridor types. In addition, polyclinics with different corridor types can be linked to each other and create new developed plans. According to corridor type, polyclinic layout plan has alternative of ‘U', 'T', 'H', 'I' type plan schemes.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WAITING AREA (FEMALE)
ENTRY
PUBLIC & STAFF ACCESS
RECEPTION

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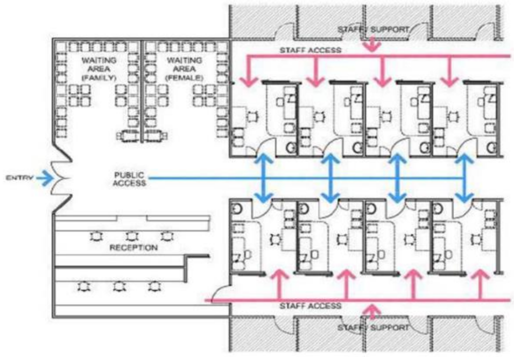
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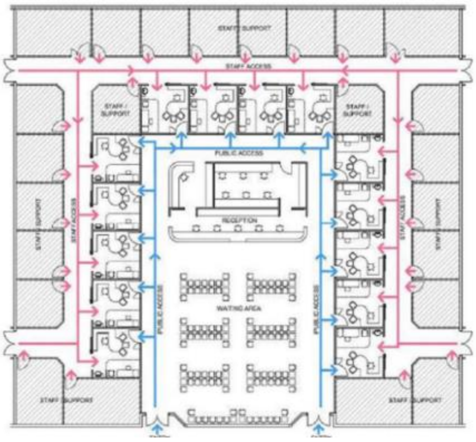
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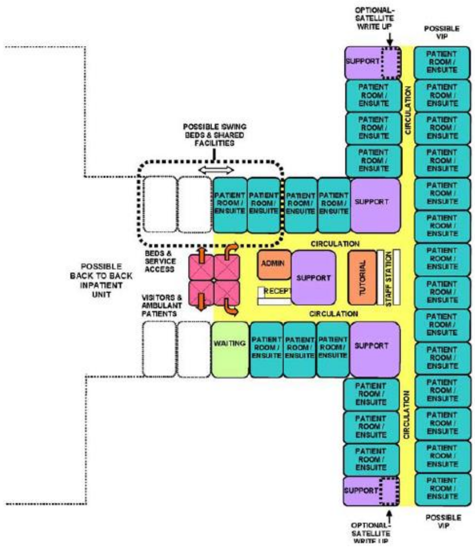
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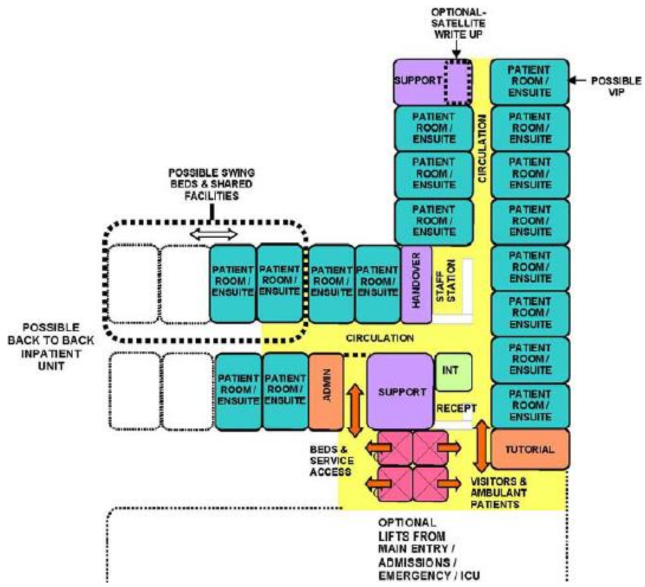
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POSSIBLE BACK TO BACK INPATIENT UNIT
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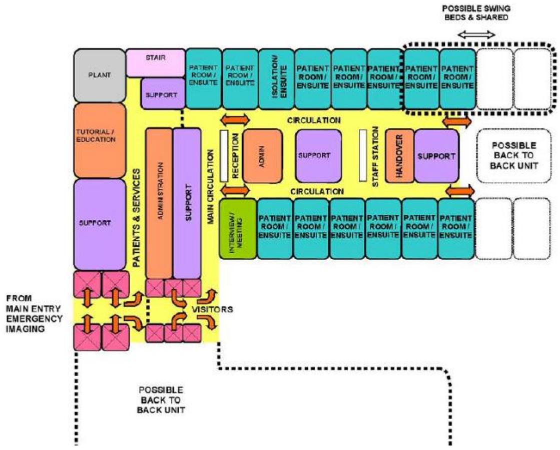
VISITORS & AMBULANT PATIENTS
OPTIONAL LIFTS FROM MAIN ENTRY / ADMISSIONS / EMERGENCY / ICU

(f)



(g)

Figure 2: Hospital Outpatient Clinics Plan Schemes (a), (b), (c), (d), (e), (f), (g) [3]

1.1. Purpose

Hospitals have a dynamic structure, but at the end of the process of transforming the inputs they receive, they are among the structures where the feedback mechanism works [4]. Hospitals are defined as social systems, socio-technical systems, systems that can adapt to the environment, and open-dynamic systems. It has a social system because it interacts with the environment, and it has a socio-technical structure because the social system and technology constantly affect each other. At the same time, it has an open-dynamic structure that can adapt to the environment and has a feedback mechanism [4]. The main purpose of the study is to create a model for alternative plan types by using the productive design methods of hospitals with a dynamic structure and to develop the optimum solution proposal by evaluating the existing designs and derivatives. By considering the external patient-centered hospital polyclinics, and considering the shape grammar, genetic algorithm, and space sequencing methods an optimum solution proposal was developed in terms of two architectural programming variables: distance and visibility. The problem discussed within the scope of the article; is to create a design assistance for hospital polyclinics that defines how the units are related to each other in terms of technology, health and hospital management.

What is intended to be realized in the design technology intersection is to rationalize the design inputs, create an optimum design base through software and use this design base in model formation.

1.2. Content

Today, the design of health structures is important in the delivery of health services, which are becoming increasingly complex. At this point, it is aimed to offer a broad perspective on hospital designs, which are among the health structures of architectural design. Various studies are carried out to improve health care and to provide a comfortable environment. This study investigates the hospital design optimization by creating spaces with minimum route overlap, minimum walking distance and high visibility for polyclinic patients. In order to obtain the ideal design, accurate data were used to obtain results through various software. In this context, computational design methods were used. The study aims to create the polyclinic architectural program creation with design research techniques considering the development process and to use a design base model production with the system developed together with various hospital design standards, needs, feedback, analyses and evidence-based method. The proposed method aims to constitute a common input for a polyclinic design. The most distinctive feature of polyclinics is the repetition of spaces. Theoritically, repetitive structures are defined as well-defined [5]. The nature of polyclinic plans can give opportunity to evaluate by the shape grammar analysis and the derivation of spaces can be defined with rules. The optimization of spaces is provided with shape grammar rules and derivated with genetic algorithms. It is essential to evaluate these plan alternatives to explore the best solution with minimum walking distance with highest visibility. Space sequence method of space syntax benefits to constitute an optimum plan solution for this study. The main research problem of the study is to determine an optimum polyclinic design solution with the assistance of rule-based software programmed with shape grammar method and evaluated with spatial sequence method.

1.3. Method

In the study, a triple linear model has been used: discover shape grammar rules, derivate with genetic algorithms, evaluate alternative solutions (figure 3).

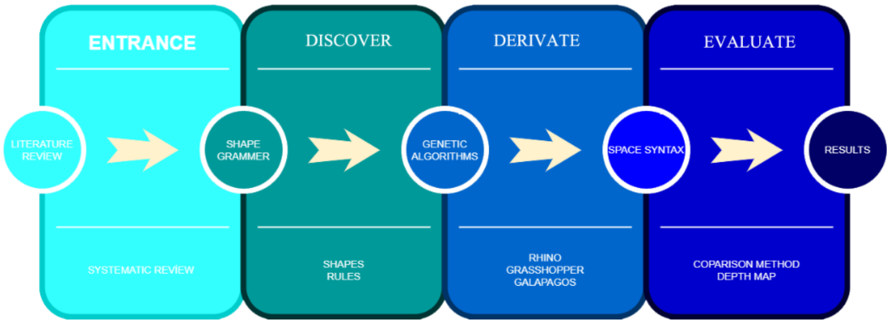


Figure 3. Method Diagram

Shape grammar, genetic algorithm and space syntax method, which are the three-stage methods specified in the study, were applied as follows: In the first phase, shape grammar rules have been discovered with the aid of rules, codes and existing designs. The dimensions of the polyclinic spaces were revealed by examining the hospital polyclinic plans within the framework of shape grammar. In this context, spatial relationships were revealed from the hospital plans examined and rule sets were established. In the seond phase, genetic algorithms were applied to polyclinic architectural program with defined shape grammar rules. All the data obtained were created by using the Grasshopper program for space production in the genetic algorithm and the model created was defined by a relationship-based optimization circuit. In the final phase, the alternative plans obtained from the shape grammar method were evaluated in terms of visibility, depth and readability to explore the best solution for minimum walking distance and visibility. In summary, shape grammar and genetic algorithm methods from rule-based designs were used in the model formation and the space sequencing method was used as an evaluation and selection method.

With the genetic algorithm, hundreds of plan alternatives from the data were created in the example of a single-aisle plan scheme. The study offers the opportunity to create separate alternatives for each plan type scheme in the following stages. The study was concluded by giving an exemplary evaluation method on how to use the space consolidation method to evaluate the visibility and depth of the obtained optimized hospital plan and existing hospital projects in the context of spatial relationships.

2. Rule-Based Design and Implementation

When rule-based design approaches are examined in the literature, different productive design techniques using shape grammar, genetic algorithms, algorithmic design, parametric design, and factor-based system approaches are examined [6], [7], [8], [9], [10], [11]. The rule-based designs that bases the method of this study are discussed below within the framework of the literature with their contribution in the process: In literature, different productive design techniques using shape grammar, genetic algorithms, algorithmic design, parametric design, factor-based system approaches are observed [6], [7], [8], [9], [10], [11]. Knight (1997) [12], classifies shape grammars into six groups: basic grammars, non-basic grammars, sequential grammars, additive grammars, deterministic grammars and unrestricted grammars. Basic grammars consist of successive sets of rules. Added rules ensure the continuity of each other. Non-basic grammars arise from steps and derivations of the previous design. In consecutive grammars, the rule is applied sequentially. It is based on the symmetrical relationship of shapes. In additive grammar, the rule set is produced by deriving the starting shape without adhering to the sequence. In deterministic grammar, the starting form is the same for all rules. Unlimited grammars, on the other hand, produce without depending on the parametric shape. Shape grammars, which can be defined mainly as a set of rules, are an analysis/analysis and reproduction technique. Although Stiny (1977)'s works [13] are among the first examples in this field, the work in which Palladio villa plans are produced [6] includes parametric shape grammar productions. It is among the first studies to be considered in terms of the analysis of an architectural design example with a shape grammar method. Algorithmic design is a design concept that expresses the production stages as a process within a rule-based system. This term has been used in 2003 for the definition of computer software that produce space and form consistent with Terzidis' architectural program building codes, typology and language within rule-based logic. In 2017, the algorithmic design was defined by Oxman [10] as the coding of clear instructions for producing digital forms (Figure 4).

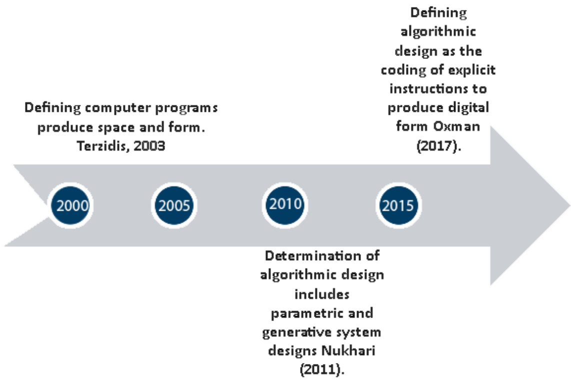


Figure 4. Algorithmic Design Time-Line

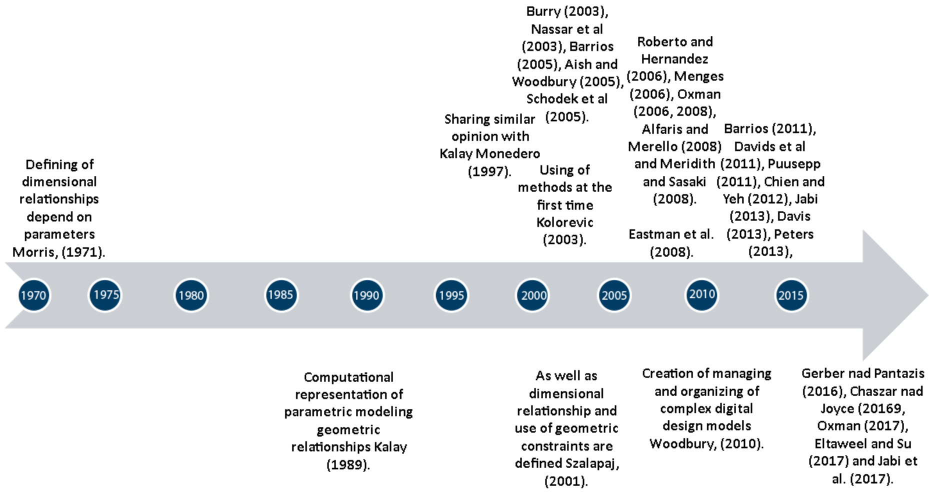


Figure 5. Parametric Design Timeline

Parametric design, is a concept that expresses the design and production stages with parameters in a rule-based system. This concept was first defined by Morris in 1971 as dimensional attachments based on parameters. Tin (1989) was expressed as a computational representation of geometric relationships, first used by Kolarevic as a method in 2003 [7]. Complex digital design models were created by Woodbury in 2010 [11] (figure 5).

2.1. Shape Grammar

In this study, the purpose is to reveal the health structure design relationship network that contains many inputs and criteria with the shape grammar technique. The shape grammar method reveals the network of relations among polyclinic units and can contribute to systematize complex health process management. In accordance with rule-based design approach, shape grammar has two types: analytical and original. Analytical grammars are sampled with traditional structures and original grammars are defined as new creations and original studies [14]. This study understands the analytical grammars within corpus of multiple hospital polyclinics and generates designs within these grammars. The allocation of generated spaces defines alternatives for design within a relationship matrix (Figure 6)

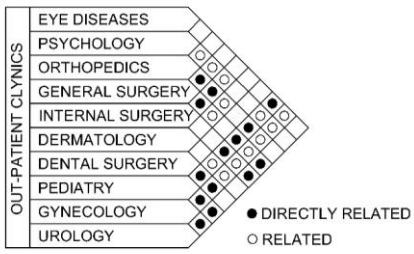


Figure 6. Polyclinic Relationship Matrix

The polyclinic units in the relationship matrix (figure 6) have a single-corridor plan scheme. Single-aisle hospital plan schemes are produced by generating rules based on the way they come together (figure 7), and within the framework of these rules, the original hospital plan scheme is given in figure 8.

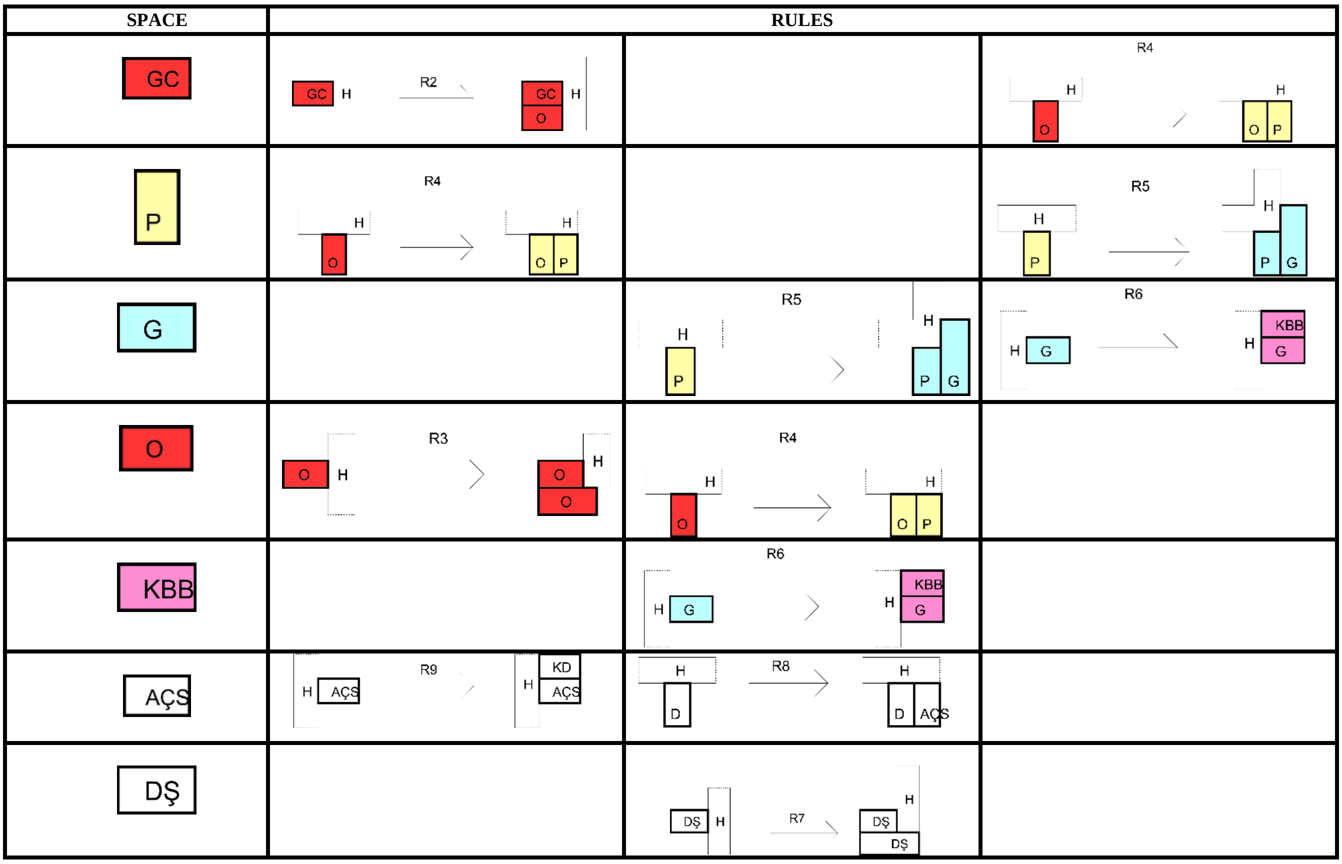


Figure 7. Rule Sets

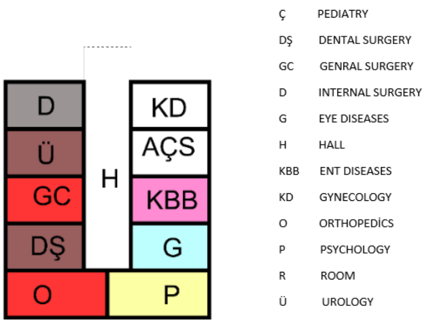


Figure 8. Polyclinic Placement with Rules.

2.2. Genetic Algorithm

Figure 9 indicates a genetic algorithm for plan productions. Accordingly; Rules were produced from the plan diagrams examined and the spatial dimensions of the polyclinics examined were interpreted within the framework of various standards and optimum space dimensions were obtained.

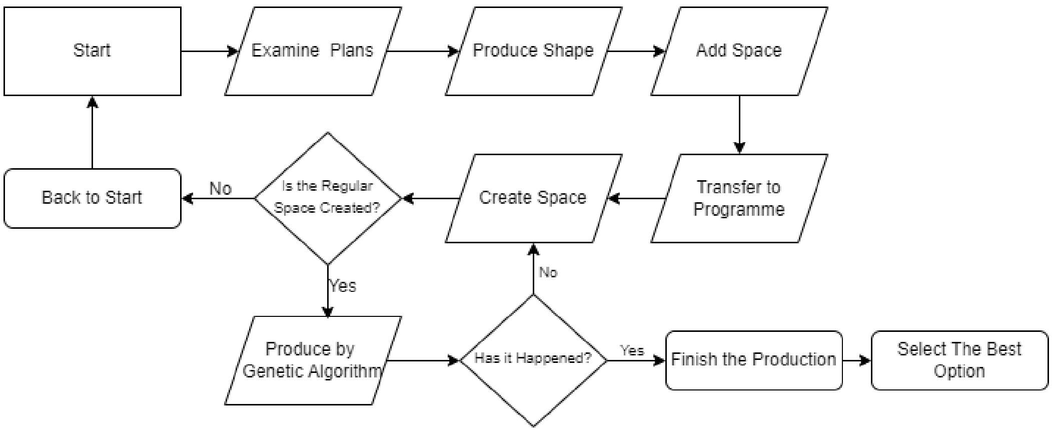


Figure 9. Production Algorithm

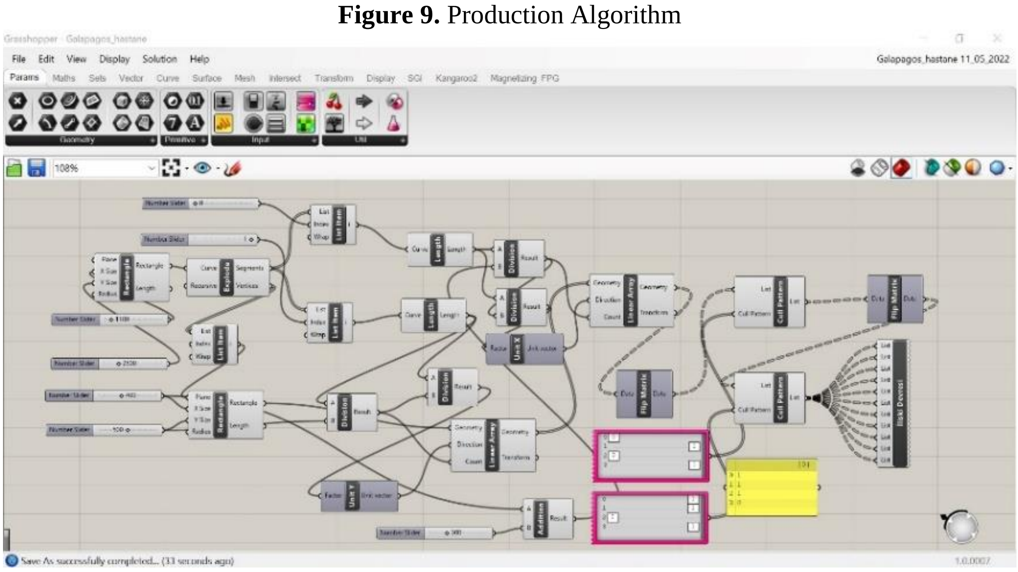


Figure 10. Model Circuit

The data on the obtained rule sets and dimensions are given in Figure 10 of the Galapagos polyclinic circuit created by entering the data that formed the basis of the grasshopper program. Here, by using the dimensions taken from different hospital plans, hospital polyclinics related to each other are grouped and it is ensured that they act within themselves and within the framework accepted as the general limit. With the produced circuit, the production of canonical space was realized. Production was completed by selecting the most appropriate plan type among the canonical optimized space productions. As a result of generation, the plan diagram in Figure 11 is given as the result product.

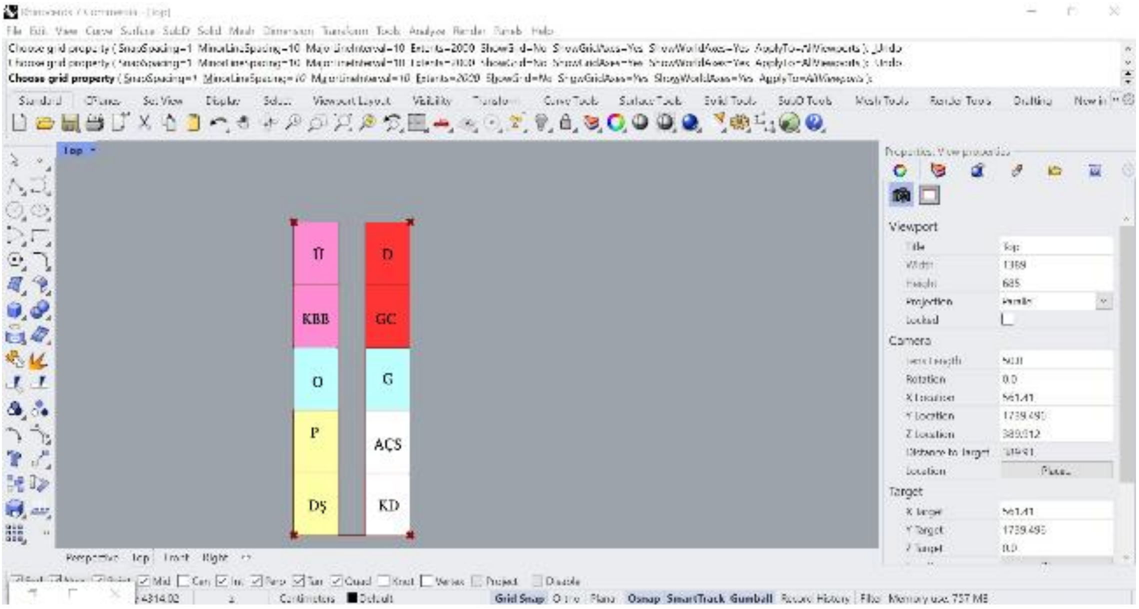


Figure 11. Selected Plan Diagram as a Result of Genetic Algorithm Generation

In Figure 12, the polyclinic unit names corresponding to the numbered spaces are given and the relations between the spaces are shown in the yellow box on the right side. For example, unit number 3 (internal medicine) is associated with unit number 4 (general surgery). The urology polyclinic, which is the number 9 unit, is associated with the internal medicine polyclinic, which is the number 3 place.

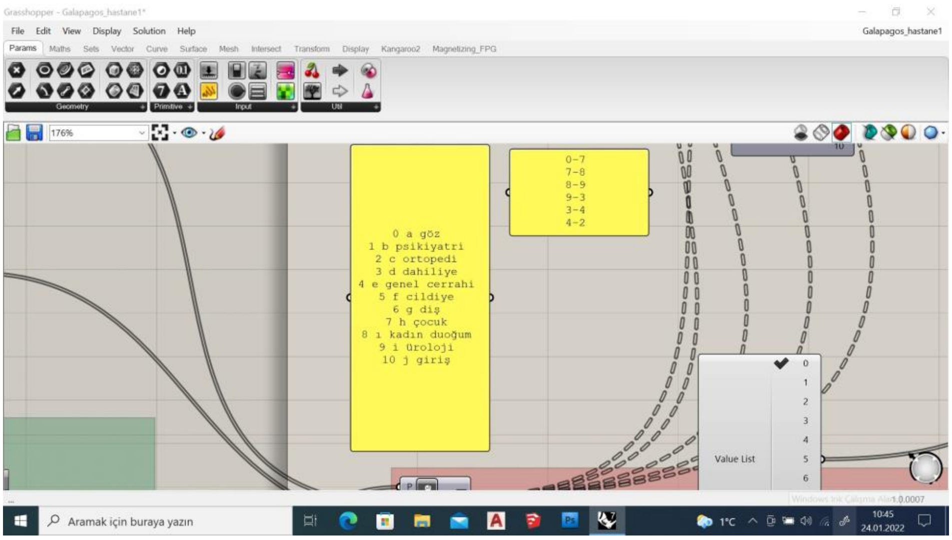


Figure 12. Polyclinic Names Assigned to Numbers and Their Relationships

In Figure 13, the circuit is made operational by entering the average dimensions on the 'X' and 'y' axis separately for the spaces defined as rectangular in the circuit. The circuit relationships created for each space relationship are given in figure 14.

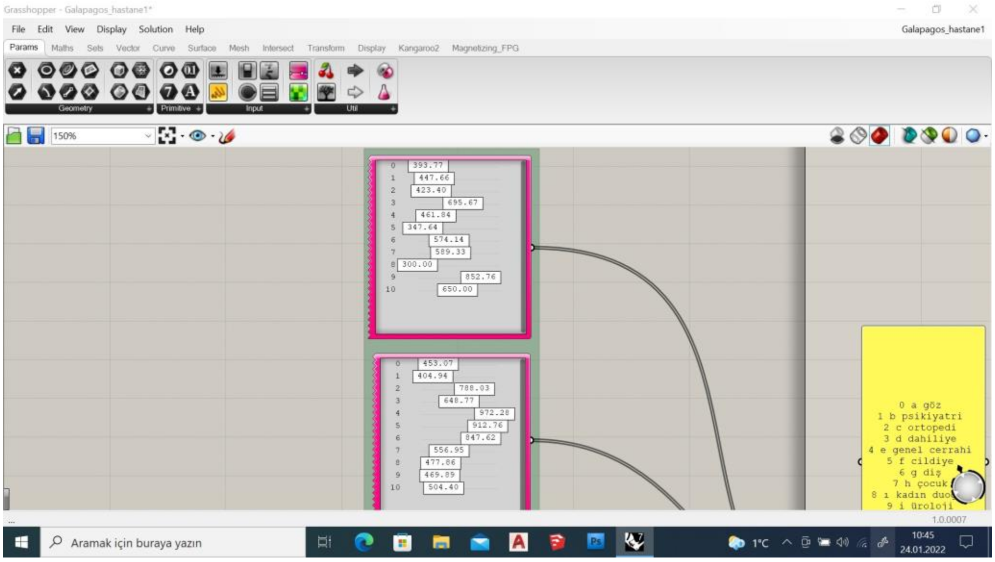


Figure 13. Polyclinic Dimension Entry

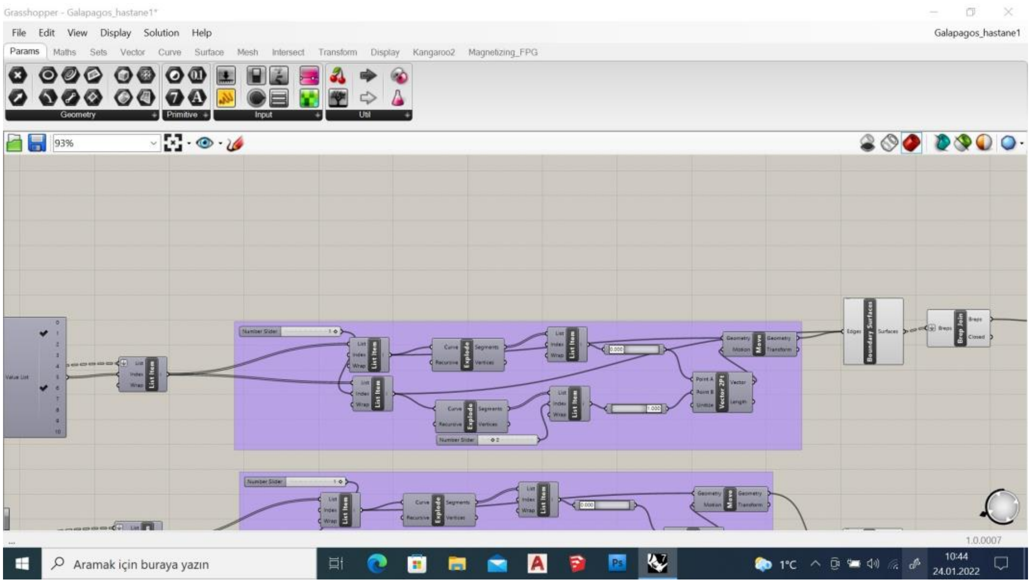


Figure 14. Relationship Circuit.

Our created circuit was enabled to produce with the Gene Pool command (figure 15), which produces a genetic algorithm. The hundreds of examples produced are shown on the screen given in Figure 16.

The spatial sequencing method was obtained from a different hospital plan. The hospital plans scheme obtained from the Ekap web-page is given as an example to define the space constellation method in this work.

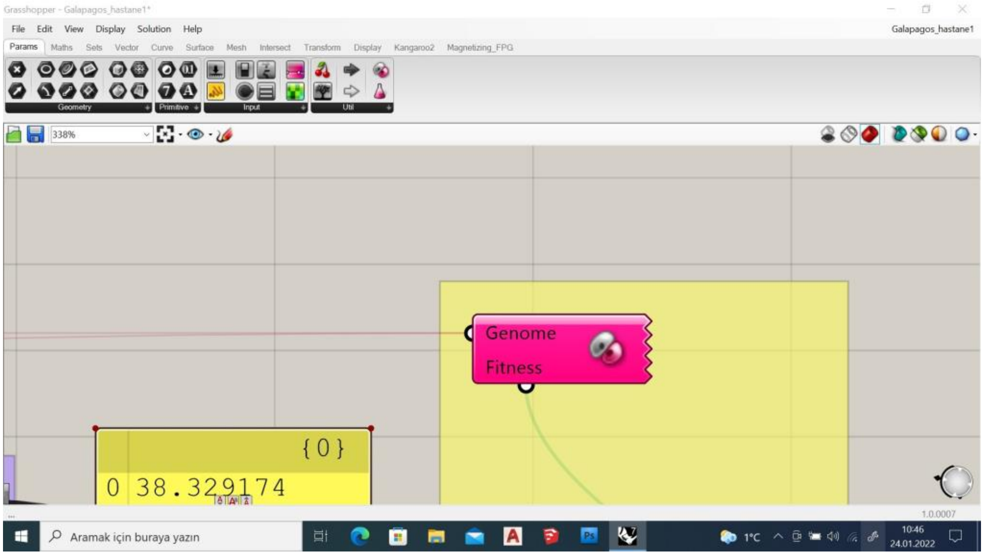


Figure 15. Genetic Algorithm Command

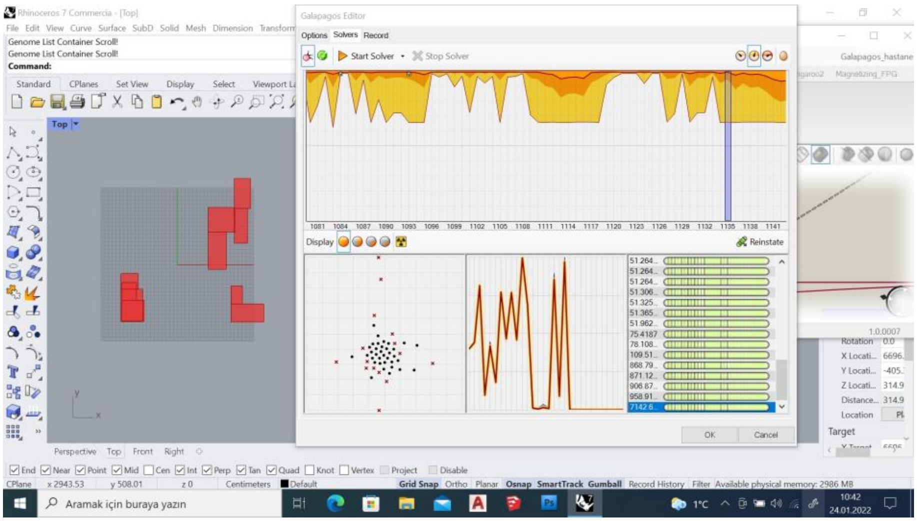


Figure 16. Genetic Algorithm Productions

2.3. Space Syntax Method

Abstract data and concrete data play a major role in the evaluation of spaces. However, it is very difficult to evaluate abstract data in an objective form. According to Hillier [15], the spatial arrangement method is a set of techniques used to explain and classify spatial formation in residential areas or structures. The aim of these techniques is primarily to examine the relationship of spatial organizations with user movements and field of view objectively. This method reveals the potential of spaces to bring users together and circulate. In this sense, the spatial constellation method, which serves to evaluate the concrete and abstract data about the space is an auxiliary tool preferred by architects to analyze spatial forms [16]. The concepts and expressions used in the analysis can be briefly defined as follows: Each space considered in the spatial constellation method expresses a knot. The relationship between spaces is expressed by edges. The relationship between the two spaces is explained in terms of neighborhood and transition.

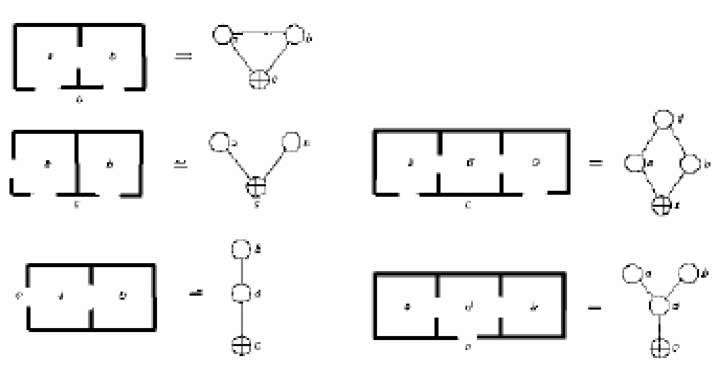


Figure 17. Transition/permeability graph (Şahin and Olğun, 2020).

In order to form the numerical expression of the syntactic structure we have considered; (1) A transition graph (neighborhood graph) (figure 17) that expresses the spatial organization of the building, (2) a depth graph (arranged transition graph) that determines the depth of each space relative to the other (figure 18). The graph method shows the relationship of the places that are transitional and connected to each other. The terms are expressed below:

- ***The graph***; is a set of points connected to each other by lines. While the point-nodes used in the method represent the spaces, the lines-edges express the transition of the connection between these spaces.

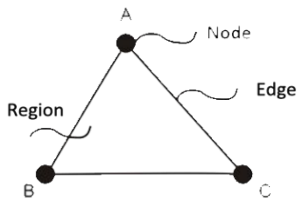


Figure 18. Example of Transition Graph Chart (Reproduced from [16]).

- ***Depth;*** is an important factor for spatial configurations. It is used in the structure to express how many steps are taken in the transition from the entrance or any space to another space (k: The total number of nodes in the graph, d: depth) (figure 19).

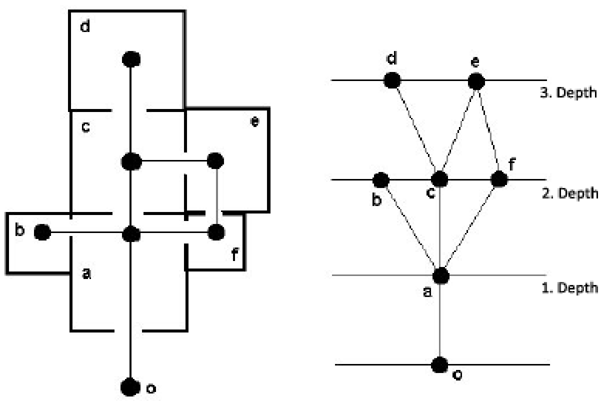


Figure 19. Transition Graph (Neighborhood Graph) and Depth Graph (Reproduced from [16]).

- **Beta Index;** Depending on the node and edge relationships of the network; numerically what kind of network the network is. The ratio of the total number of edges to the total number of nodes. If this value is β<1, the structure is wood, if it is β=1, the loop, and if it is β>1, this graph shows the complex circuit property.

- **Beta Index**; (B=E/V= Beta Index: Graph Edge/ Graph Node) (figure 20).

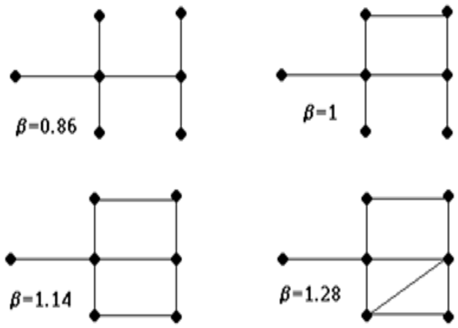
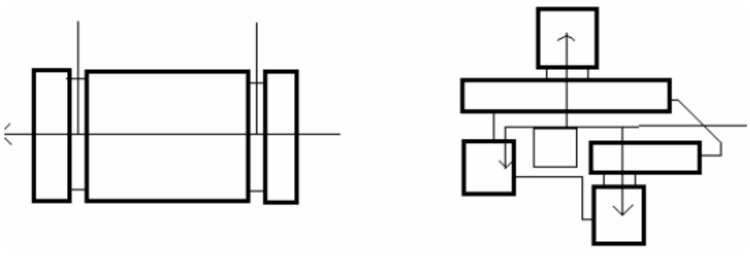


Figure 20. Beta Index [16])

- ***Gamma* Index*;*** Depending on the relationship density of the network elements; gives the "Connectivity" ratio of the network numerically. It provides data on whether the building form is compact or piecemeal. A value of 1 indicates complete connectivity, while a value of 0 indicates complete disconnection between the network elements (figure 21).

• Gama Index:

$$G = \frac{E}{(v2 - v)} / 2$$



High Low

Figure 21. Gamma index building format relationship [16]).

- ***Connectivity*:** It is a measurement of the number of neighboring places directly connected to the space. Each direct step is a local distance that measures the correct number of distances. This local criterion is the most basic knowledge of the comprehension of space. The most important point of the concept of connectedness is the reflection of the form of space based on the visual perception it creates in the mind of the person using the space. In short, it gives the relationship of each place with other spaces.

- ***Visual integration:*** Space syntax theory defines shallow spaces with high integration value as evacuation points as spaces with high visuality and permeability. These points are integrated areas where there is a lot of social interaction. On the other hand, spaces with lower social interaction are places with deep and low integration. They are numerical values that indicate that a space integrates and separates from the system.

- ***Visual mean depth:*** One of the most important relationships in the Spatial Constellation Method is the concept of depth. Depth occurs when passing through multiple intersecting spaces to get to a place. If the space to be reached has a small value in terms of changing direction, then the depth is called "shallow", and if it has a high value, it is called "deep". What is important here is that the relationship of each space with all other spaces in the system can be shown as a value. In Figure 22, the plan scheme produced as a result of shape grammar with the spatial sequencing method and the optimized plan schemes produced by using the genetic algorithm with the help of rhino/grasshopper are given comparatively:

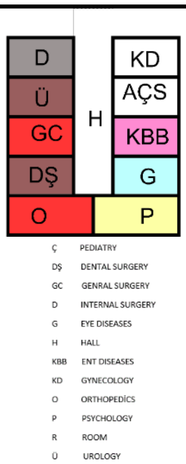
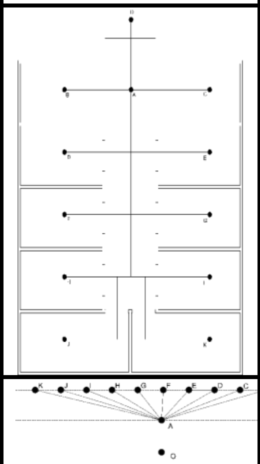
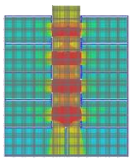
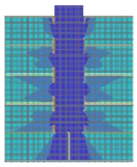
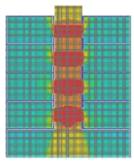
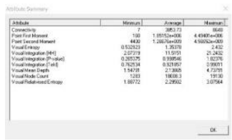
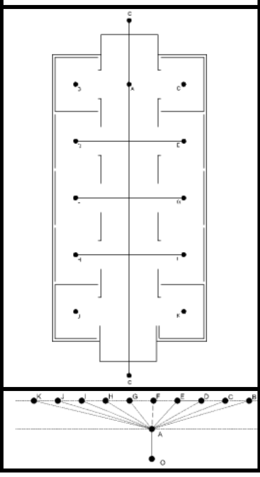
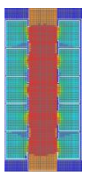
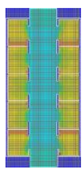
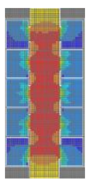
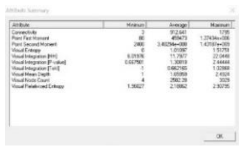
PLAN SCHEME	GRAPH SCHEME	CONNECTIVITY	DEPTH	VISUAL INTEGRATION	RESULT SUMMARY
					
					

Figure 22. Analysis with Space Syntax

According to these results; in the graph chart; β<1 is the structure tree, β=1 is the loop, and β>1 is the complex circuit. The network; whether it is a tree, loop or complex circuit; defines whether the holistic form of the building is suitable for linear, cyclic or composite forms. According to the table given in Figure 22, the β values of the plan schemes produced by shape grammar and the plan diagrams produced by genetic algorithm gave the same result (β: 16/12=1.33 > 1). The structure has shown the property of complex (composite form) circuitry. It is a structure in linear form (Figure 22). According to the gamma index; A value of 1 indicates complete connectivity, while a value of 0 indicates complete disconnection between the network elements. Space syntax theory defines shallow spaces with high integration value as evacuation points as spaces with high visuality and permeability. These points are integrated areas where there is a lot of social interaction. On the other hand, spaces with lower social interaction are places with deep and low integration. The value of 0.0606 ($16/12^2$-12/2=0.0606) that we have received indicates complete disconnection (figure 22). If the space has a small value in terms of depth, then the depth is called "shallow", and if it has a high value, it is called "deep". A scheme of plans derived from the grammar of the form, which takes a high (2.138) value in the calculation of average depth; The plan scheme derived by the genetic algorithm has received a lower value (1.659) in its production and this plan scheme is shallower than the form grammatical plan scheme (Figure 22).

3. CONCLUSION

Architecture produces spaces that shape life with rules. The designs based on the original designs guide the designer in the production of buildings. In our study, the three-stage method of shape grammar, genetic algorithm and space syntax methods were applied. Firstly, hospital polyclinic plans were examined within the framework of shape grammar and polyclinic spaces were revealed with their dimensions. By obtaining the dimension and area relationship, the average space dimensions were extracted and the hospital plans examined were revealed with their spatial relations in this context and rule sets were created. Shape grammar method was carried out by following the adaptation of the space dimensions and traditional plan mentioned in Erem and Ermiyagil's study [17]. All the data obtained were used in the genetic algorithm to produce space by using the Grasshopper add-on and Galapagos module of the Rhino program and a model was defined by a circuit. This circuit is defined as a relationship-based optimization model (relation-based optimization 'Rbo'). With a genetic algorithm, hundreds of plan alternatives from the data were created in the example of a single-aisle plan scheme. In the later stages of the study, it was aimed to create separate alternatives for each plan type scheme (U, H, T, L, etc.). In this study, where canonical building design methods were used together for all these purposes, it was seen that the optimized plan schemes produced from polyclinic plan schemes were in a shallower structure than the rule-based plan schemes. These were located in the space class where social interaction was high in terms of their structure, were more efficient in terms of visibility and density and were suitable for the growing possibility of hospital polyclinics.

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CONFLICT OF INTEREST

The authors stated that there are no conflicts of interest regarding the publication of this article.

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