# GENERATIVE DESIGN RECOMMENDATIONS FOR THE HISTORICAL MARDİN HIGH SCHOOL AND GAZİPAŞA PRIMARY SCHOOL BUILDINGS, TURKEY

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## 1. Introduction

Cultural assets that shed light on many important developments in human history and the history of civilizations establish a connection between the past and future events. In this regard, civilizations are documents and symbols reflecting the urban and architectural style of the era they were established in, along with their economic, social, and cultural accumulation. It is a responsibility that every citizen should be aware of to consciously preserve and pass on these cultural values considered as a common heritage across generations [1].

Buildings gradually lose their original functions over time due to social, economic, environmental, and technological factors. Abandoned buildings that have lost their function face the danger of demolition. Reuse becomes a frequently preferred option in many types of structures to ensure their continued existence, which means that many buildings of historical and cultural significance, embedded in societal memory with their architectural identity, can reach the present day through methods of reuse.

Conservation interventions, such as repurposing, can impact the spatial arrangement, structural system, facade, and technical infrastructure of a building. For example, the Feshane building in Istanbul was transformed from a textile factory into a congress center, its spatial arrangement was changed, and interventions were made on its facade that were not suitable for the original structure. Such transformations can negatively affect the identity of the original building. A similar example was seen in the Sirkeci Train Station building in Istanbul. While the building was transformed into a touristic center within the framework of urban transformation, its spatial arrangement and technical infrastructure were modernized. The CerModern building in Ankara was also converted from a former railway depot into a cultural center; its façade was significantly altered, and its technical infrastructure was completely renewed. Although such interventions increase the risk of losing the original character of buildings, successful implementations can both preserve the historical identity of the building and make it functional. In this study, unlike previous studies, the effect of re-functionalization on the building facade was examined and suggestions were made in this context.

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Mardin, located in the southeastern Anatolia region of Turkey, is one of the rare cities that has preserved its historical and cultural structures to the present day. The traditional architecture of Mardin exhibits examples that are rarely found within the borders of Turkey. This situation is due to both Mardin's geographical location and its topographical structure. When studies on traditional Mardin structures are generally considered, it is observed that while research has been conducted specifically on churches and monasteries, mosques and complexes, traditional houses and palaces, there have been very limited studies specifically on educational buildings. In addition, generative systems and computational sciences have not contributed sufficiently to conservation interventions in this field and there is a significant gap in the literature in terms of its use as a methodology, especially for historic buildings in Turkey. This study aims to examine relationships between productive designs and to present a productive design method that integrates different systems [2].With the advancement of technology, various numerical-based methods are used in architectural shaping. In this study, shape grammar and genetic algorithms, which are productive approaches, were employed. Shape grammar defines the design language of spatial composition and generates different alternatives through a rule system. Like languages composed of words and rules that combine these words, shape grammar consists of rules pertaining to shapes and their spatial relationships. Within the scope of this study, only rule sets and the grid-based spatial grammar method were utilized. Genetic algorithms, based on the principles of natural selection, are an eligibility method; it was John Holland who established its fundamental principles [3].Genetic algorithms (GA) are based on the idea of survival of the fittest derived from evolution in nature. In genetic algorithms, data is encoded under the genes guise. Through crossover and mutation operations on these encoded genes, the most suitable results are achieved. There have been many scientific studies on genetic algorithms, and the method has been developed and applied in various fields such as production, facility layout, scheduling problems, construction technologies, optimization, vehicle routing, job planning, architecture, and many others [2]. The study examines Mardin High School, the first educational structure from the Ottoman period in Mardin, and an annex, Gazipaşa Primary School, located in the southeastern Anatolia region of Turkey. Alongside its distinctive features, the functional changes of the high school structure, which also embodies characteristics specific to the Mardin region, were addressed in terms of its architectural qualities. The interventions, applications, and adaptive reuses carried out in accordance with restoration projects over time were critically evaluated for their compatibility with the historical identity of the building. In pursuit of this aim, survey and restoration projects from the Mardin Cultural Heritage Protection Regional Board and local archives regarding the school structure were reviewed, and a condition analysis was conducted comparing its current state with its original form [4]. Using the genetic algorithm method in the analysis, comparisons were made, and alternative typology suggestions were developed accordingly. Changes in window and door openings have occurred over time due to the deterioration of the structure and its adaptive reuse. Therefore, the study focuses on limited window and door typologies based on available data on facade openings that can be accessed through the change process. This approach enables the generation of contemporary alternative door and window typologies based on data related to traditional original carpentry when changes or additions are made to the structure. The study highlights that many buildings undergoing restoration today often deviate from traditional sustainability concerns in facade elements, posing a significant challenge for architectural continuity in traditional contexts. Furthermore, the underutilization of a scientific method such as genetic algorithms to address this issue in traditional contexts was identified as a problem in the study. From this perspective, the objective was to prepare new door and window typologies with genetic eligibility functions for architectural design processes aimed at conservation interventions, such as restoration or adaptive reuse, using the genetic algorithm method. Additionally, the study demonstrates the contribution of genetic algorithms, used as an optimization tool, to the field of design. This method provides an opportunity to transfer original values to future generations. Early decision-making in the architectural design process regarding alternative door and window typologies for new structures in the region is crucial for architectural sustainability.

## 2. Materials and methods

Firstly, general information about generative systems, shape grammars and genetic algorithms was provided. This was followed by an analysis of the historical background, architectural features and transformation process of Mardin High School and Gazipaşa Primary School in Mardin by focusing on the door and window typologies of the facade elements. In particular, by using genetic algorithm and shape grammar methods as a methodology, the accuracy of the changes and interventions that occurred on the facades as a result of conservation efforts carried out over time was determined and new typologies were produced. In the study, shape grammars were used to define rule sets, while genetic algorithms determined eligibility functions. A field study was conducted to suggest new door and window typologies based on eligibility values derived from the genetic algorithm method. This study was centered around the analyses of the plan and facade of Mardin High School and Gazipasa Primary School. The school complex was encoded in the field study, and facade carpentry types were categorized from the plans, encompassing various door and window frame types [2]. To define the rule set for facade formation, a module was first established by measuring a dormer window, an architectural element on the facade. During this process, the facades of other traditional Mardin buildings were analyzed. It was found that these facades often feature window openings that can be adjusted in size by combining smaller modules. The research identified the smallest opening among these facades as the dormer window, which typically uses an illumination module of 40 x 45 cm. Thus, the module size was set at 40 x 45 cm. Factors such as light efficiency or location were not taken into account in determining this module because the main purpose here was to create a grid plane with a module with a certain ratio based on the grammar of form. In this respect, the buildings were analyzed, and the grid plane was prepared with reference to the size of the skylight with the smallest opening. By replicating and assembling the defined module, a 6 x 8 grid plane was created in two dimensions [2]. This grid was based on the floor height of Mardin High School, ranging from 3.00 to 3.10 meters. To match this height, a vertical arrangement of 8 units was chosen, resulting in the selection of a 6 x 8 grid plane.

Before starting the algorithm, several parameters influencing the facade design needed to be determined in the study. The parameters were:

- Transparent surface (0),
- Openable transparent surface (1),
- Non-transparent wall surface (2),
- Non-transparent openable wooden surface (3),
- Non-transparent openable wooden surface of a different type (3a)

- Non-transparent openable iron surface (4)
- Non-transparent openable iron surface of a different type (4a) [2].

The window and door typologies of the buildings were genotypes and phenotypes according to the determined parameters. The representation of genotypes was created by transferring the numerical data of the above parameters to the grid plane, while the representation of phenotypes was created by using the reflection of the numerical data of the parameters in the external appearance of the joinery. The eligibility value of each typology was determined, followed by crossbreeding and mutation. The new typologies obtained through crossbreeding should fall within these eligibility values. However, the typologies subjected to mutation are not required to fall within the eligibility value range. Some coding was done for eligibility values:

- x: Number of modules reflecting the parameters in the genotype of the window or door typology
- y: Total number of modules in the genotype of the window or door typology
- z: Eligibility value of the typology
- $z = x / y$ [2]

In the final stage, identity cards were created for each structure to transfer the information pertaining to the structure. Subsequently, the unique window and door typologies examined were transferred through sections of the structure. This ensured that the analyzed window and door typologies in the structure were clearly expressed. Finally, optimal alternative typologies were presented for each window and door typology addressed using the genetic algorithm method.

### *2.1 Generative systems approach*

In general, "generative" refers to the capacity to create or the ability to generate new ideas. Generative design, specifically, is defined as an approach that emphasizes the process of creation rather than the final outcome. A generative design system, therefore, is a tool that aids users in the procedural aspect of design, supporting the generation of creative outputs. The extent of the system's generativity is influenced by the designer's capability to produce innovative work and expand their design perspective [5]. With advancing technology today, the importance of generative design methodologies is increasingly recognized. Generative design overcomes the monotony of products created through computers and avoids this ordinariness.

Computational thinking, on the other hand, is an algorithmic thinking process based on mathematical and logical operations, which can be defined as a problem-solving process in this context. It uses various levels of abstraction to identify and solve problems. The identified problems and solutions are formulated in a way that the information processing mechanism can successfully accomplish.

This processing mechanism can work with the possibilities offered by technology, as well as solving the problem through its own reasoning and cognitive processes, benefiting from human knowledge and experience. Typically, in generative design systems, the process of product formation is achieved through symbolic computation. The specified symbols define rules through specific parameters, which are used to generate new products.

The conceptual foundation of the study establishes two main generative design systems currently in use. The characteristics of these generative systems will be explained and compared within the scope of the study.

### *2.1.1. Genetic Algorithms*

Genetic Algorithms (GAs) are inspired by the field of genetics and operate as a search and optimization method based on the principles of natural selection. GAs are one of the sub-concepts of an evolutionary architectural approach. They mimic biological processes in nature based on Darwin's principle of survival of the fittest. Ideas such as the ability of those who adapt to the environment to continue their lineage and obtaining superior individuals from superior parents have formed the notion that crossover methods applied differently in solving complex problems will produce better solutions [6]. Recently, they have been extensively used, particularly in solving complex problems such as form generation and functional analysis in architectural design. For example, genetic algorithms have been used in architectural façade designs to develop solutions that optimize sustainable energy use. In one study, genetic algorithms were used to optimize performance criteria such as light and heat control of buildings and optimal façade arrangements were obtained [7]. Vural (2005) conducted optimization studies for mass production planning using the genetic algorithm method [6]. Similarly, Gökçe (2023) proposed façade elements for traditional U-plan houses in Diyarbakır with the help of genetic algorithms [2]. Thus, optimal façade solutions were obtained in line with structural and aesthetic criteria. GAs not only provide solutions to many scientific problems but also enhance the creativity of designers and facilitate exploration into richer design spaces. This concept was first introduced by Bagley in 1967 [8]. However, an important study in this field was conducted in 1975 under the leadership of John Holland, a psychologist and computer science expert at the University of Michigan [9]. The processing steps of GAs proceed in the following stages:

- Selection process,
- Formation of the initial population,
- Crossover operation,
- Mutation operation,
- Calculation of eligibility function,
- Formation of new generations and completion of the cycle [2].

The process steps of GAs are defined as follows:

- Codification of solutions: A fundamental prerequisite for the development of genetic algorithms is the formulation and description of each individual through codes.
- Creation of the initial population: A set of solutions encompassing all possibilities is generated.
- Calculation of the eligibility value: To achieve the desired result, the eligibility function of the solution must be determined. The population is assessed based on this criterion, thus ensuring that all individuals in the generation approach the eligibility function value. Individuals that do not meet this criterion are eliminated. Moreover, a high eligibility value within the solution group enhances the

likelihood of reproduction, survival, and transmission to subsequent generations [10].

- Selection process: During this stage, individuals with the eligibility values are selected and assembled into the matching pool [11].
- Crossover process: Crossing defines the formation of new individuals by modifying the gene combinations possessed by the parents at a given point (Figure 1).
- Mutation: This process is conducted to enhance genetic diversity and/or preserve existing diversity [12]. Through mutation, new chromosomes are derived from existing ones. When the current genetic diversity lacks certain desired data, mutation enables the discovery of the desired solutions.
- Completion of the cycle and new generation formation: Once the cycle has been repeated for the desired number of iterations, populations of individuals meeting the eligibility criteria are generated, marking the completion of the cycle.

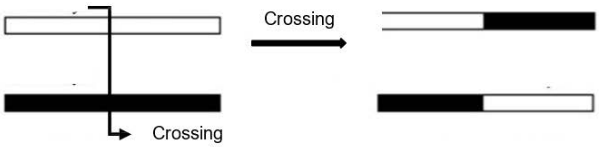



*Figure 1. Crossing between two types [7].*

Genetic algorithms (GAs) use terminology from natural evolution. Two distinct concepts are utilized to define individuals: genotype and phenotype (Figure 2).

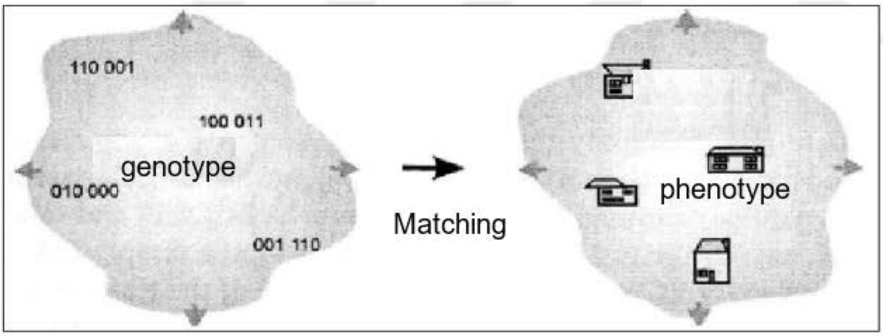



*Figure 2. Matching between genotypes and phenotypes [13].*

A genotype refers to the genes that determine the genetic characteristics of a person [14]. Genetic changes occur at the genotype level. Phenotype is defined as the expression of the genotype. In genetics, hair color, eye color, etc. While the coding of features as a gene creates the genotype, these features are determined in the individual as blue eyes, blonde hair, etc. Observation in this way is called phenotype [15].

The processes involved in generating new generations within the framework of a genetic algorithm are commonly referred to as genetic operators. These operators play a crucial role in expanding the solution space, thereby facilitating the exploration of more viable solutions [16]. The spectrum of these operators encompasses tasks such as parameter encoding, eligibility value computation, initialization of the initial population, selection, crossover, mutation, and termination operations. While numbers or letters can be utilized for encoding, individuals are generally represented as strings comprised of numbers 0 and 1 [6]. The selection of coding methods may vary depending on the specific nature of the problem under consideration. In the context of this study, genotype coding is expressed using numerical values.Moreover, nowadays, genetic solutions (GA) and artificial intelligence (AI) are both used to stimulate creativity in architectural design and to solve complex solutions. However, their working principles and application methods are quite different. We can summarize the main differences between genetic algorithms and artificial intelligence in the context of architectural design as follows:

- Artificial intelligence can automatically generate designs using deep learning models, neural networks, etc. Genetic algorithms work under the control of the designer.
- While AI relies entirely on machine learning, genetic algorithms use the principles of randomness and evolution.
- AI deep learning models give better results as they are trained. Genetic algorithms start over every time.
- AI needs very large datasets, while genetic algorithms can work with smaller data.
- Artificial intelligence generates designs automatically, while genetic algorithms generate designs with designer parameters.
- In architecture, artificial intelligence can produce completely new and original designs. Genetic algorithms refine existing design parameters.
- Therefore, artificial intelligence works more autonomously, while genetic algorithms work under designer control and are based on parameters.
- In the present study, by using the genetic algorithm method, the aim is not to restore the old functions and geometries in the historical building, but to make the historical texture a reference point and resource for new designs in line with the national renovation policy.

### *2.1.2. Shape grammar*

The term "grammar," first used by Chomsky, was further developed in the 1970s by George Stiny and James Gibs (1977) to describe the algorithmic structure of production systems in a rule-based formalism. Algorithms are employed to formalize the solution of existing problems [17,18]. The primary objective is not to reduce design to a formulaic level but to generate new alternatives using specified rules. These rules reinterpret the existing architectural language to produce different products. Designers can obtain different compositions by utilizing specific rules and operations on the form set.

Various operations on shapes lead to the creation of different products. Techniques such as boolean operations (union, difference, intersection) on forms, euclidean transformations, and parametric changes enable the generation of new shapes (Figure 3).

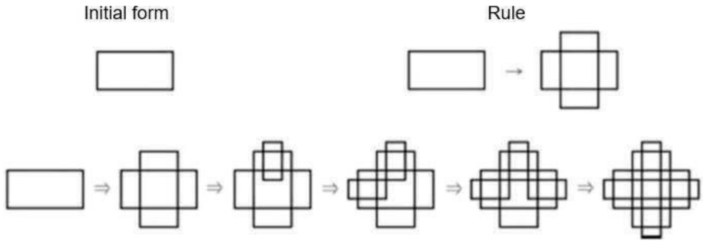



*Figure 3. Applying the rule to the initial shape [19].*

Shape grammar is widely used in various art disciplines, particularly in architecture, to represent, understand, and create original design languages and styles. They can:

- Create entirely original design languages,
- Model transformations within existing design languages,
- Analyze design languages,
- Facilitate the formation of another design language using existing ones,
- Generate new design languages from existing ones [20].

In architectural terms, shape grammar has been prominently used, especially in residential design. One notable example is Frank Lloyd Wright's Usonian houses, developed in 1981 by Koning and Eizenberg. The study was conducted on 11 Usonian houses, utilizing rectangular prisms as the basic unit (Figure 4).

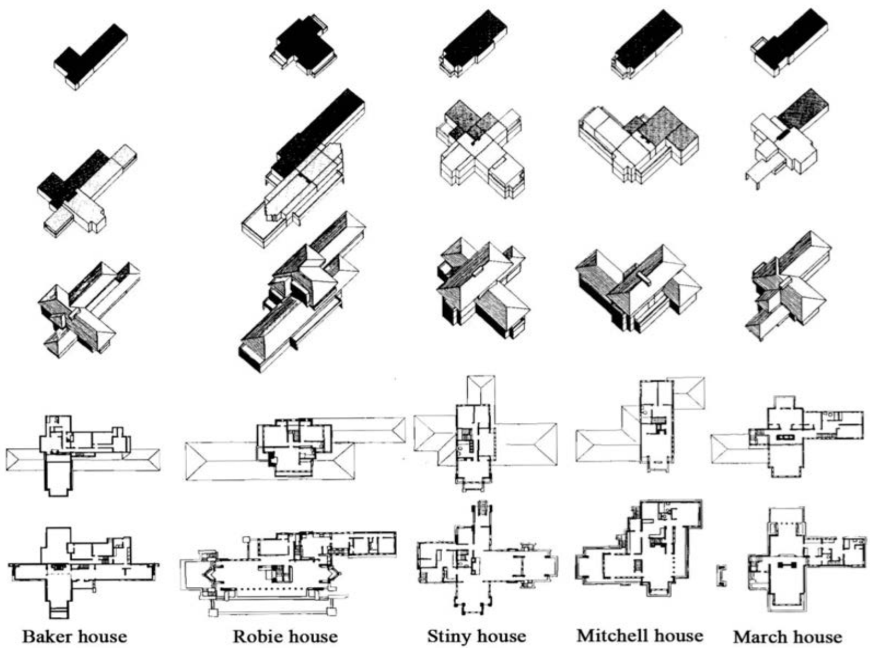



*Figure 4. Existing and generated rural houses [21].*

In the case of blocks with fixed height and variable dimensions of length and width, the fireplace is a significant parameter. During the production phase following the fireplace placement, there are 18 established rules. These rules enabled the production of 89 different rural houses [21]. In the study, three rural houses were generated under the names Stiny, Mitchell, and March. These houses are unique creations containing similar rules to the designs of Wright's rural houses. Parametric shape grammar was developed for the production of these houses; the developed grammar clarified and made the composition created in Frank Lloyd Wright's rural houses comprehensible [21].

### *2.2. The history and architectural features of Mardin High School*

Mardin city is positioned on one of the main routes connecting Anatolia to Syria and is an important crossroads of Upper Mesopotamia. The historical texture of the city is composed of streets, bazaars, religious, social, and educational buildings, along with traditional houses. Its monumental structures and traditional residences, as well as its fortress, reflect the cultural heritage left by the significant civilizations that once ruled there, making it one of the prominent cities that still embodies these values today. Traditional Mardin houses, with their narrow streets, resemble an open-air museum [22] (Figure 5a, b and c).

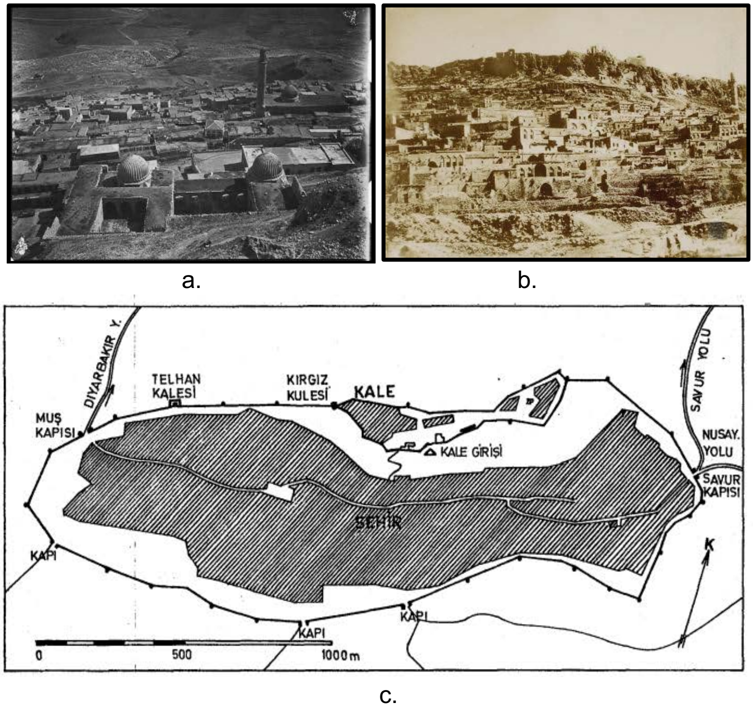



*Figure 5. a. and b. Aerial photographs, 1904 [23] (left and center); c. Mardin city walls and castle [24] (right).*

One of the significant architectural elements contributing to the dense urban fabric is the educational building. The schools evaluated in this study were constructed in the 19th and 20th centuries and are located in the Upper Mardin region where the historical texture of the city is preserved. The structures include Mardin High School and its annex, the Gazipaşa Primary School (Figure 6).

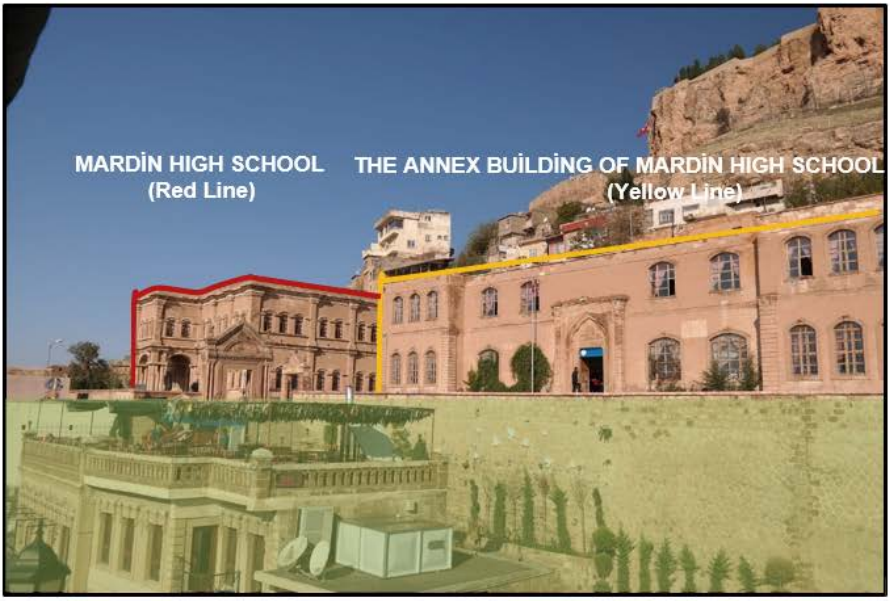



*Figure 6. The current appearance of Mardin high school and its annex building [25].*

Mardin High School was built on the land of the Muzafferiye madrasa (school) and mosque dating back to the end of the 13th century.

The *sülüs* inscription above the entrance gate indicates that the high school was inaugurated in July of Hijri 1318 (AD 1900-01) [26]. It is the oldest educational structure built during the Ottoman period in Mardin and intended to function as a High School. It is situated on a high terrain overlooking the Mesopotamian Plain due to the sloping terrain of the city on Mardin Mountain (Figure 7a and b). The exact construction date of the building is not precisely known. However, there are records indicating that it was built between 1892-1895 [27]. In 1932, it was used as a middle school and later as Mardin High School and Commercial High School. Following the literacy campaigns initiated after the alphabet reform in 1932, the building was expanded to include Gazipaşa Elementary School in its courtyard. In 1982, it was converted into a girls' vocational high school. Today, it serves as the Institute of Maturity. According to the inscription on the school gate, it underwent major renovations in Hijri 1318 (1902 AD) by the then Diyarbakır Governor Celal BEK. In 2012, both buildings underwent restoration through a historical transformation project initiated by the Mardin Governorship. Additionally, the building constructed adjacent to the High School, which has differentiated over time, began to be used as Gazipaşa Elementary School.

a.

b.

*Figure 7. a. Mardin High School was built on the grounds of the Muzafferiye madrasa (school) and mosque (highlighted in red) [28]; b.1889 engraving of Mardin city skyline showing Muzafferiye Madrasa (highlighted in red).*

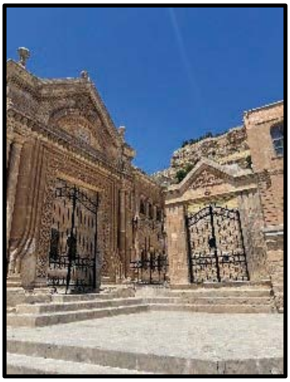
The structure is constructed from cut stone in the Seljuk style.

It is distinguished by two monumental stone-decorated crown gates and entrances. These two monumental crown gates exhibit different styles as they were built in different periods. The main building, the High School building, has a simple entrance gate, while the additional structure built in 1932, which is now the elementary school, features a traditional monumental portal entrance [29].

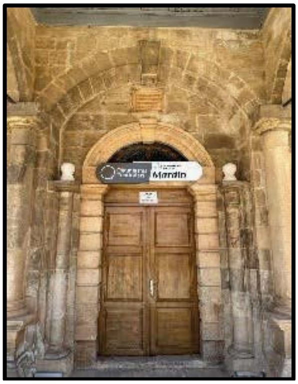
The architectural style is known as Neoclassical and is considered an impressive example of Ottoman period architecture.

The decorations and details used in the interior and exterior spaces of the school reflect the aesthetic understanding of the period [27] (Figure 8a, b and c). The main high school building is two stories high, and the entrance is on the southern facade.

a.



b.

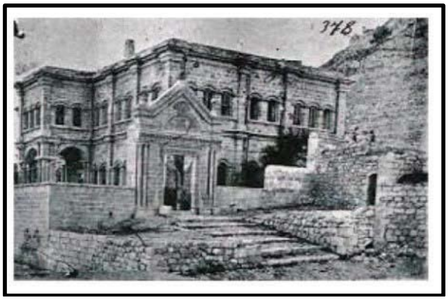



c.

*Figure 8. a. Mardin high school building; b. Mardin high school monumental entrance; c. wooden door at the monumental entrance of the school.*

The building has a rectangular plan with a T-shaped corridor system in the middle. On the first floor, all four sections are used as classrooms, while on the ground floor, the southeastern section is divided into three equal parts and is used for administrative purposes. Therefore, the building has a total of 7 classrooms, with 3 classrooms on the ground floor and 4 classrooms on the first floor. The building's natural lighting and ventilation in the corridor are provided directly through twin windows opening to the east and west facades, as well as indirectly through windows opening into the classrooms. The entrance door on the southern side of the building opens onto a terrace garden overlooking the valley. Wet areas of the building are separate and are found outside the main structure. To ensure maximum illumination in the classrooms, the building is equipped with twin and triplet windows of equal dimensions repeated along the facade, regardless of orientation. Window sizes are uniformly dimensioned irrespective of the direction. The facade, distinguished by stonework, features various decorative motifs, reliefs, and arches in the upper section. The building has a generally symmetrical design and details such as domes and bell towers on its roof. Inside, the school retains architectural features of its era with spacious halls, high ceilings, and large windows. The stairs, decorations, and wooden details inside the building are also noteworthy. With its features, it is considered one of the significant symbols reflecting the historical texture and cultural richness of Mardin [28] (Figure 9a and b).

a.



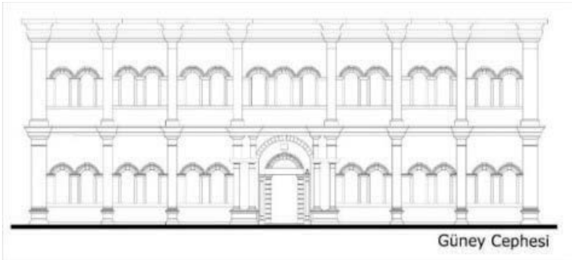

b.

*Figure 9. a. A photo of Mardin high school after restoration; b.an old photo of Mardin high school [27].*

The single main entrance of the building is located on the southern facade. The entrance, which protrudes outward and is adorned with four columns on each side, adds richness to the facade. The building is constructed from white Mardin stone. All facades of the building consist of repeating twin and triplet windows. The size of each window that forms the twin and triplet windows are all of similar dimensions. The windows are surrounded by small columns and arch-like decorations. Apart from the entrance section of the southern facade, the remaining sections are formed by the repetition of twin windows. The repeated twin and triplet window groups in this facade are divided by columns. These columns continue along the facade in sizes that are close to each other, while the corner columns are larger in size. All the windows have rounded arches (Figure 10a, b and c). On the eastern facade of the building, there is a repetition of twin and triplet windows. On the left side of this facade, it is also possible to see the south entrance. The classrooms are located where the triplet windows align on the eastern facade, and corridors are located where the twin windows align (Figure 11a, b and c).

The western facade is characterized by direct symmetry to the eastern facade. Similar to the eastern facade, the western facade also features a repetition of twin and triplet windows. On the western facade, classrooms are located where the triplet windows align, and corridors are situated where the twin windows align. Similar to the eastern facade, the repeating groups of twin and triplet windows on the western facade are divided by columns. These columns maintain similar dimensions along the facade, while corner columns are larger in size (Figure 12a, b and c). Despite not receiving direct sunlight, the north facade does not differ in terms of window sizes and density compared to the other facades. However, due to its construction on sloped topography, the building is protected from unwanted north winds. Twin windows repeat on both sides of the north facade. All twin windows on this facade are located in classrooms.

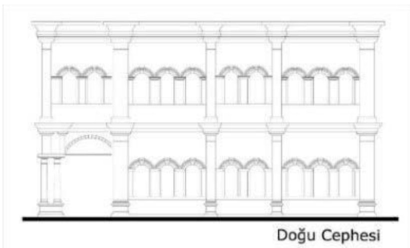
The door in the middle of the facade was used to connect it to another building to the north, but it has lost its function today. The circular-shaped window above the door differs from the overall outline of the building. Repeating twin window groups on the north facade are divided by columns. These columns maintain similar dimensions along the facade, while corner columns are larger in size (Figure 13a, b and c).




a.

b. c.

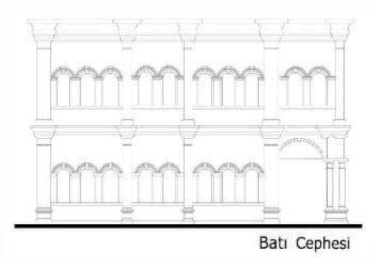
*Figure 10. a. Mardin High School south façade showing twin and triplet windows; b. The south facade of Mardin High School under restoration (center); c. Photograph of the south facade of Mardin High School after restoration (right).*




a.

b. c.

*Figure 11. a. The eastern facade of Mardin High School showing the south entrance and twin and triplet windows; b. The eastern facade of Mardin High School under restoration; c. Photograph of the east facade of Mardin High School after restoration.*

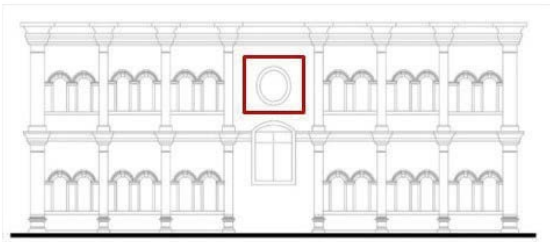



*a.*

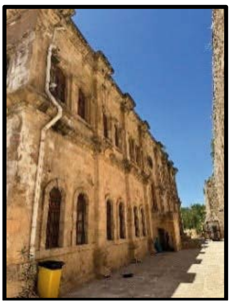
b.

c.

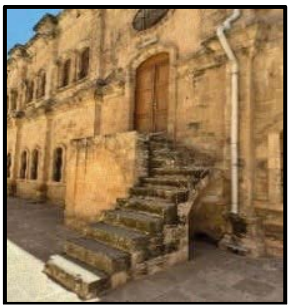
*Figure 12. a. Western facade of Mardin High School showing twin and triplet windows; b. the west facade of Mardin High School under restoration; c. the west facade of Mardin High School after restoration.*



a.



b.



c.

*Figure 13. a. North facade of Mardin High School showing twin windows and one circular window above door (highlighted in red); b. and c. images of the north façade of Mardin High School from different angles.*

The construction of the additional building, used as Gazipaşa Primary School, was initiated in 1892 by the chief architect named Lole. In the II Constitutional Period, in 1907, it was opened as a residence by a wealthy person named Cebbur from the Ancient Syriac Community. The building was used as a residence for many years. Since 1934, the building has been used for educational purposes and is now known as Mardin Merkez Gazipaşa Primary School; it is located in a common courtyard with the Maturation Institute. This building hosts educational activities in 10 classrooms(Figure 14). The building is designed in a rectangular plan similar to the main structure, oriented east-west. Access to the building is through a heavily decorated crown door reached after 7 steps on the south facade. A large hall arranged in the east-west direction and classrooms around the hall form the main scheme of the plan. The building has four floors; the composition of each is given below:

*Figure 14. Views of Gazipaşa Primary School from different angles.*

- Ground and 1st Floors: Originally intended for cellar and storage, currently used as residential and storage.
- 2nd Floor: Accessed through a large door from the street into a spacious hall with 8 rooms.
- 3rd Floor: This floor contains 3 rooms.
- 4th Floor: This floor features 10 rooms, each adorned with carved stones, with the decoration of each room-distinct from the others. The entrances to the halls and the interiors resemble a museum-like setting [30].

The additional building of the high school was originally constructed as a single-story structure. However, in 1964, an additional floor with similar plan characteristics to the ground floor was added according to the requirements of that period. The protruding part on the east side was arranged as a terrace, and later, around the early 1990s, the first-floor extension was incorporated into the building. This change is evident from observable differences in construction techniques such as window sizes and material usage, as well as from archival records [4] (Figures 15a and 15b).

### 3. Formation of productive facade elements at Mardin High School

In the prepared study, initially, plan types and facade openings of the buildings were analyzed. Through genetic algorithms and shape grammar, guiding needs for applying rules for new door and window typologies to be produced were identified. Therefore, in this study, window and door typologies were analyzed based on restoration projects accessible from the Mardin Conservation Board. The table below illustrates the window and door typologies found in the buildings (Figure 16).

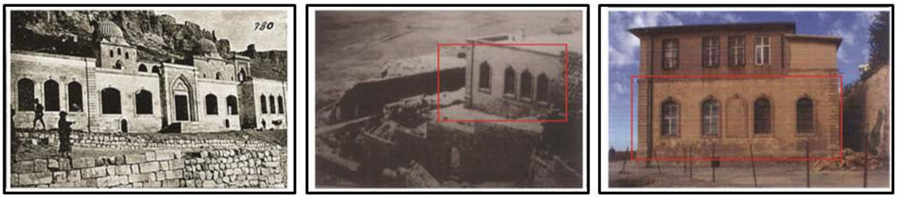


*Figure 15a. The archival photographs clearly show that the original state of the additional building was single-story (highlighted in red) [4].*

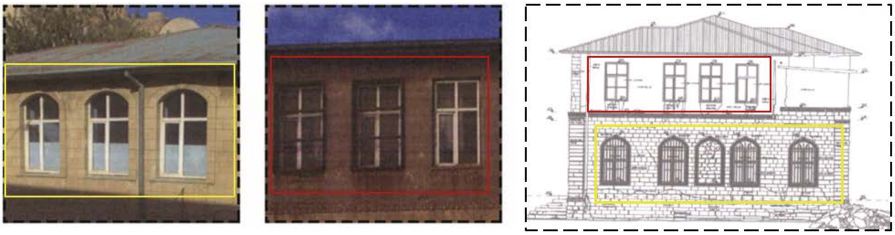


*Figure 15b. The window types on the west facade were added to the ground floor in 1964 (highlighted in yellow), and the window types added to the first floor on the east facade in the 1990s (highlighted in red) [4].*

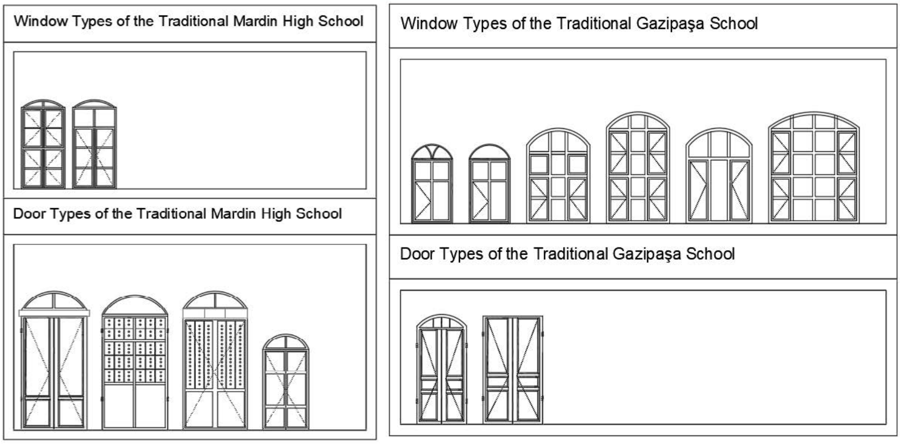



*Figure 16. Examined window and door types of Mardin High School (left) and Gazi-paşa Primary School (right).*

Typological studies were conducted based on the specified window and door openings, and the openings on the facade were illustrated with concrete data. The examined facade openings were abstracted with the determined dormer window module [2]. The dictionary elements shown below were used in determining the grammar language (Figure 17).

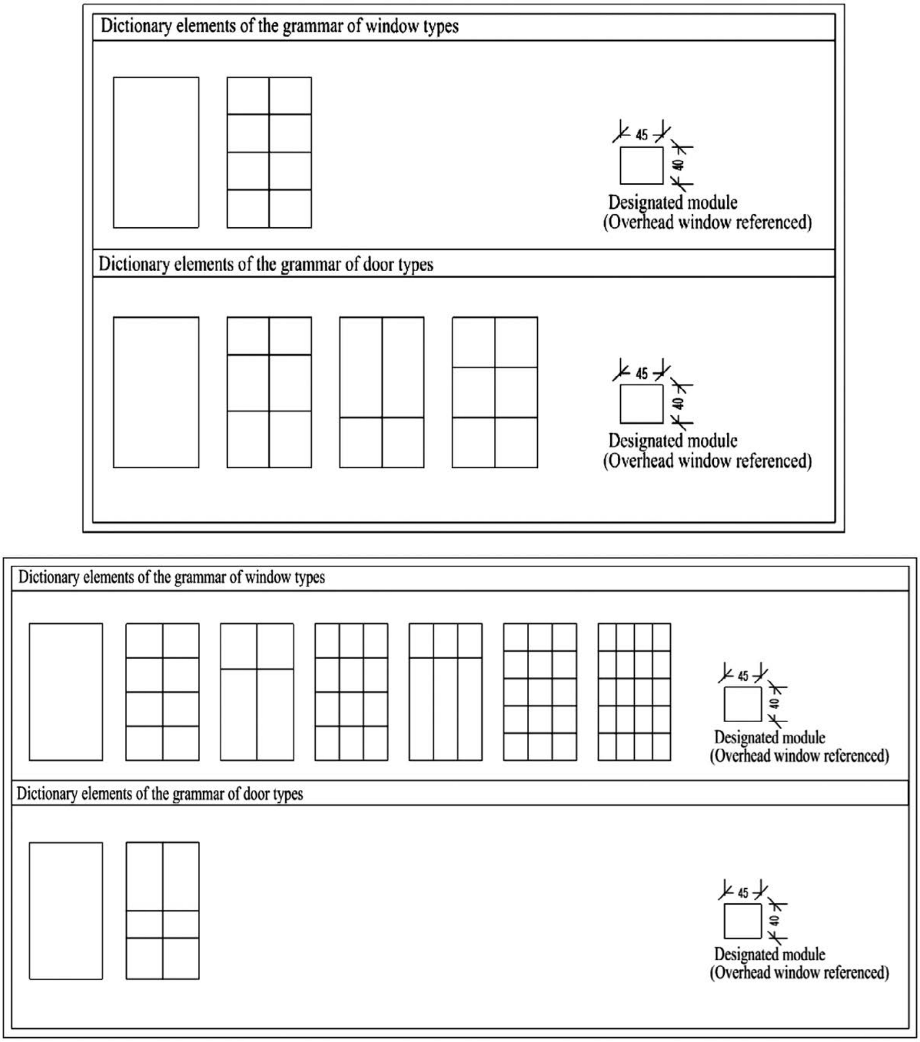



*Figure 17. Dictionary elements of grammar.*

In the study, a grid system was developed for analyzing and producing traditional house facades in two dimensions.

The upper window dimensions on the facade were measured, leading to the creation of a module to define the rules for facade formation sized at 40 x 45 cm. With this module, a 6 x 8 grid, also with dimensions of 40 x 45 cm, was established based on the floor height of the structures.

Notably, the form generated by the shape grammar is considered a genotype in genetic algorithms. Adjustments to the parameters within the genetic algorithm influence the solution time, the cluster where the solution is identified, and the selection of individuals. Consequently, this study identified seven parameters that influence facade design [2].

These parameters are:

- Transparent surface (0),
- Openable transparent surface (1),
- Non-transparent wall surface (2),
- Non-transparent openable wooden surface (3),
- Non-transparent different openable wooden surface (3a),
- Non-transparent openable iron surface (4),
- Non-transparent different openable iron surface (4a) [2].

In the cross windows of each type of housing from the unit squares located on the grid plane, there should be an x number of unit squares, transparent surfaces (0) and from these transparent surfaces, a y number of unit squares, openable transparent surfaces (1) or a z number of unit squares, non-transparent surfaces (2).

The doors of each housing type should have an x number of unit squares of non-transparent openable wooden surfaces (3) and at least a y number of unit squares of these non-transparent openable wooden surfaces should be different types of non-transparent openable wooden surfaces (3a) or a z number of unit squares of non-transparent openable iron surfaces (4) and at least a t number of unit squares of these non-transparent openable iron surfaces should be different types of non-transparent openable iron surfaces (4a). Each joinery typology of the houses was crossed and mutated in pairs.

The new typologies obtained as a result of the crossover must be between conformity values. Mutated typologies do not have to be within the conformity value range. The range of conformity values is expressed as follows [2].

- x: Number of modules reflecting the parameters in the genotype of the chopping typology
- y: Total number of modules in the genotype of the chopping typology
- z: Eligibility value
- z: x / y [2].

Since the joinery typologies of traditional Mardin houses generally use 85-90 cm wide and 170-200 cm high windows, the width size for medium-sized windows was determined as 90 cm in alternative window production. For doors, since doors with a width of 90 cm and a height of 200 cm are frequently used, the standard door size of 90-200 cm was preferred.

### *3.1. Genetic algorithm for facade analysis of Mardin High School*

In the study, the building data for Mardin High School and Gazipaşa Primary School were transferred, and a facade analysis study was conducted using the genetic algorithm method.

A separate identity card was created and tabulated for the data of each building. The algorithm flowchart for the study is shown in Figure 18.

In this study, 2 window and 4 door types were examined in the structure belonging to the Mardin high school that was analyzed. These typologies were transferred to the prepared grid substrate and encoded according to defined parameters.

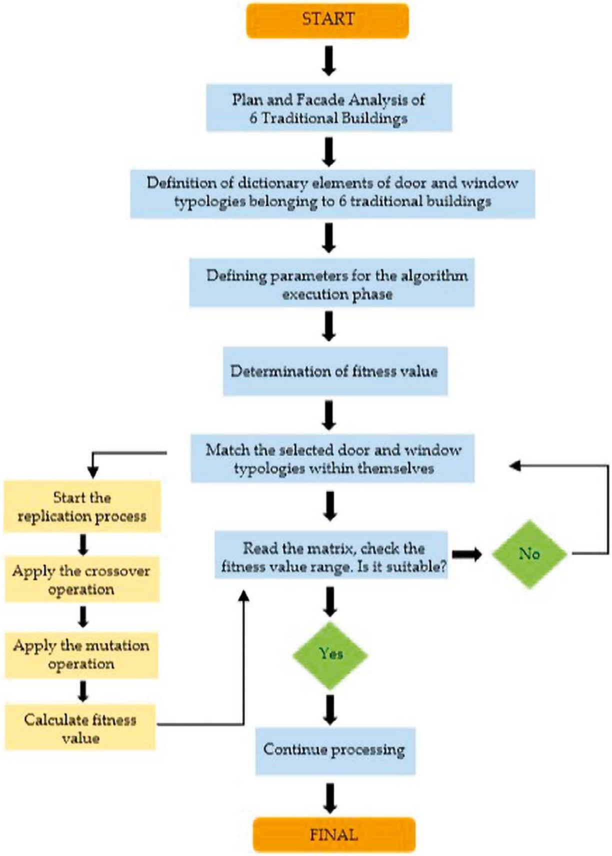



*Figure 18. Schematic algorithm.*

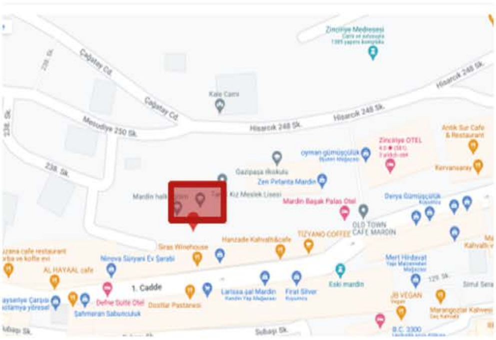
From the selected window typologies, windows were randomly crossed within themselves, and doors were crossed within themselves and subjected to mutation. Through this crossover, new typologies with appropriate eligibility values were obtained. Consequently, 10 new typologies were created for windows and 11 new typologies for doors.

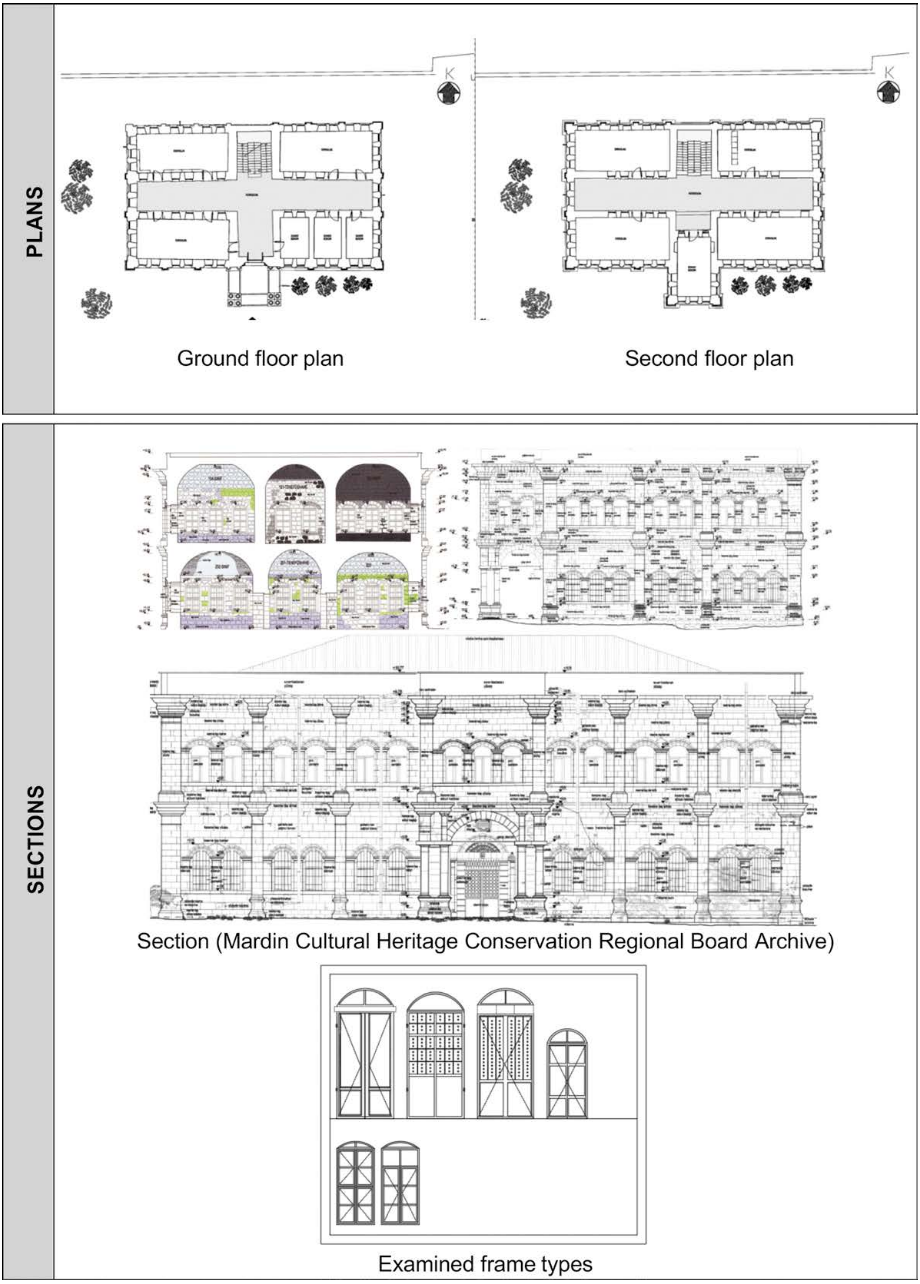
In this study, 6 window and 2 door types were examined in the structure belonging to the Gazipaşa school that was analyzed. These typologies were transferred to the prepared grid substrate and encoded according to the specified parameters. Among the selected joinery typologies, windows were crossbred and subjected to mutation randomly among themselves, while doors were similarly crossbred and mutated. As a result of this crossbreeding, new typologies with suitable eligibility values were obtained. Consequently, 18 new typologies were created for windows and 4 new typologies for doors.

In the study, 30 different window and 15 different door typologies were obtained through genetic algorithm analysis specifically applied to historical educational structures in Mardin. It was concluded that this study allows the generation of numerous window typologies compatible with traditional architectural language. The significance of this method in forming facade typologies of buildings in different climatic regions was highlighted based on the findings.

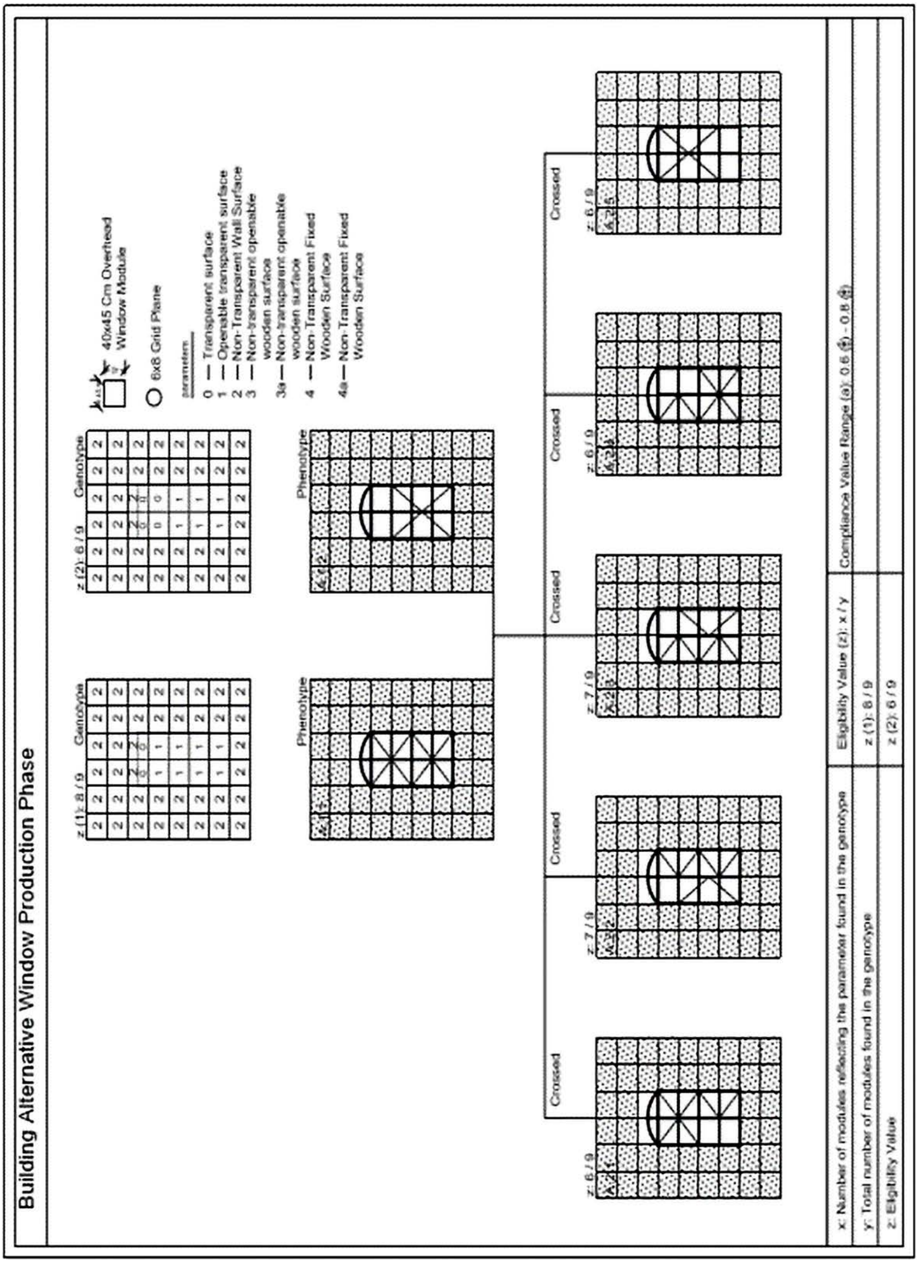
Identity information about Mardin high school is given in Table 1.

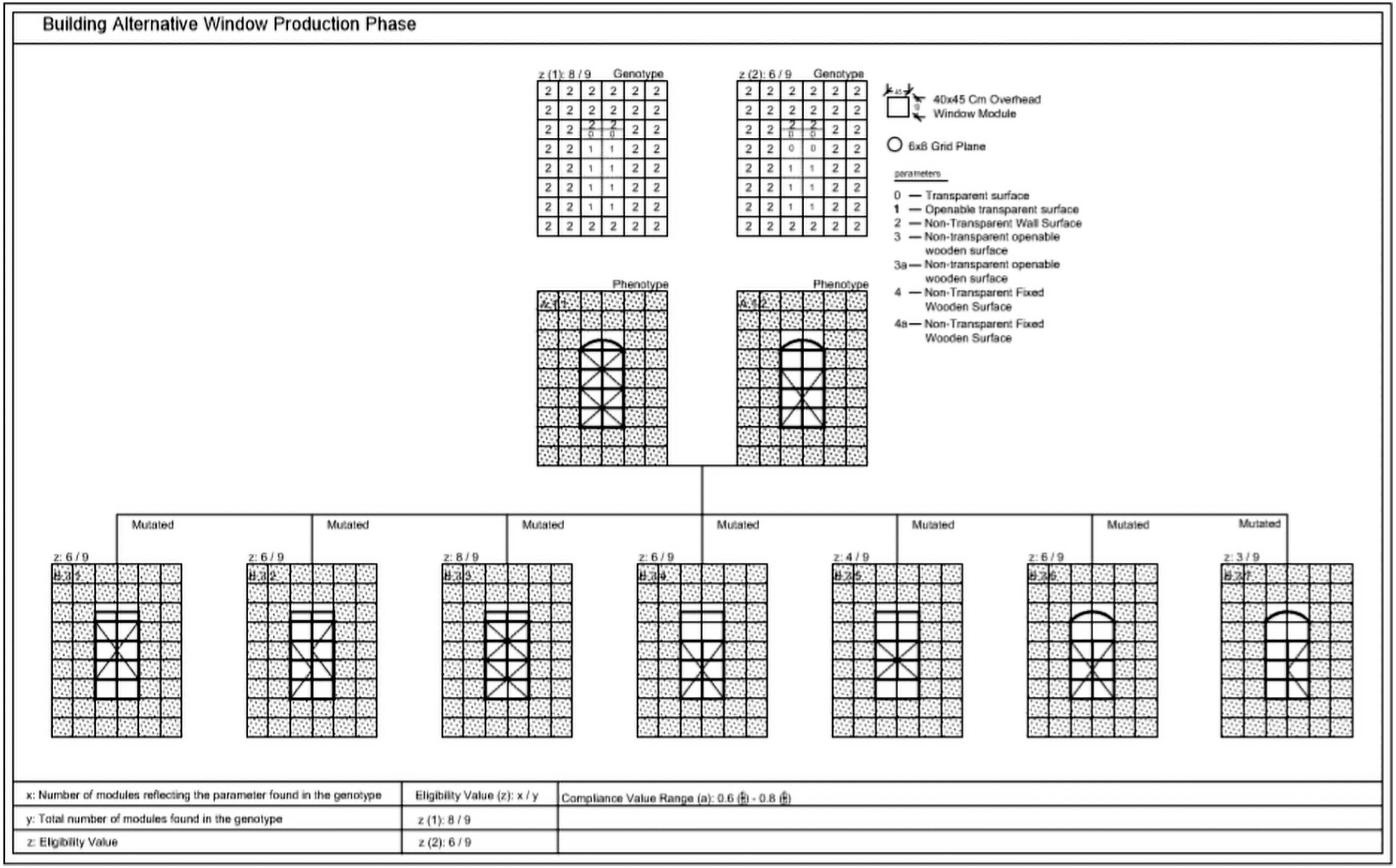
*Table 1. Identification data regarding the Mardin high school building*

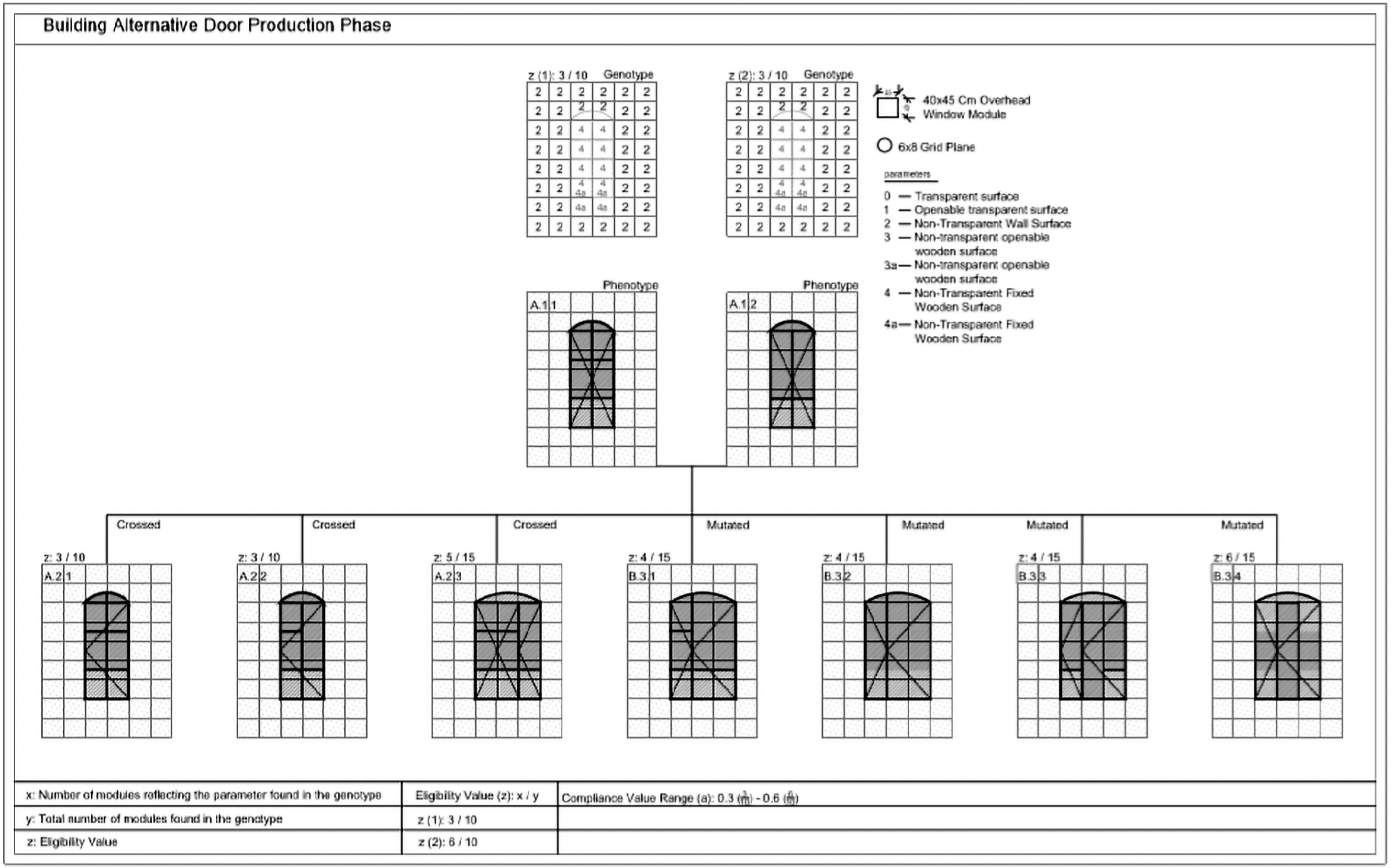
| | **ADDRESS: MARDIN HIGH SCHOOL BUILDING** |
|---|---|
| |  Location on the map   Map data ©2024 Google |
| **IMAGES** |  Images |


PLANS
Ground floor plan
Second floor plan
SECTIONS
Section (Mardin Cultural Heritage Conservation Regional Board Archive)
Examined frame types

As a result of the cross-referencing conducted on Mardin High School, 10 new typologies for windows and 11 new typologies for doors are shown in Figure 19.




Building Alternative Window Production Phase
z (1): 8 / 9 Genotype
z (2): 6 / 9 Genotype
40x45 Cm Overhead Window Module
6x8 Grid Plane
parameters
0 — Transparent surface
1 — Openable transparent surface
2 — Non-Transparent Wall Surface
3 — Non-transparent openable wooden surface
3a — Non-transparent openable wooden surface
4 — Non-Transparent Fixed Wooden Surface
4a — Non-Transparent Fixed Wooden Surface
Phenotype
Phenotype
Mutated
z: 6 / 9
z: 6 / 9
z: 8 / 9
z: 6 / 9
z: 4 / 9
z: 6 / 9
z: 3 / 9
x: Number of modules reflecting the parameter found in the genotype
y: Total number of modules found in the genotype
z: Eligibility Value
Eligibility Value (z): x / y
z (1): 8 / 9
z (2): 6 / 9
Compliance Value Range (a): 0.6 - 0.8


Building Alternative Door Production Phase
z (1): 3 / 10 Genotype
z (2): 3 / 10 Genotype
40x45 Cm Overhead Window Module
6x8 Grid Plane
parameters
0 — Transparent surface
1 — Openable transparent surface
2 — Non-Transparent Wall Surface
3 — Non-transparent openable wooden surface
3a — Non-transparent openable wooden surface
4 — Non-Transparent Fixed Wooden Surface
4a — Non-Transparent Fixed Wooden Surface
Phenotype
A.1 1
Phenotype
A.1 2
Crossed
Crossed
Crossed
Mutated
Mutated
Mutated
Mutated
z: 3 / 10
A.2 1
z: 3 / 10
A.2 2
z: 5 / 15
A.2 3
z: 4 / 15
B.3 1
z: 4 / 15
B.3 2
z: 4 / 15
B.3 3
z: 6 / 15
B.3 4
x: Number of modules reflecting the parameter found in the genotype
y: Total number of modules found in the genotype
z: Eligibility Value
Eligibility Value (z): x / y
z (1): 3 / 10
z (2): 6 / 10
Compliance Value Range (a): 0.3 - 0.6

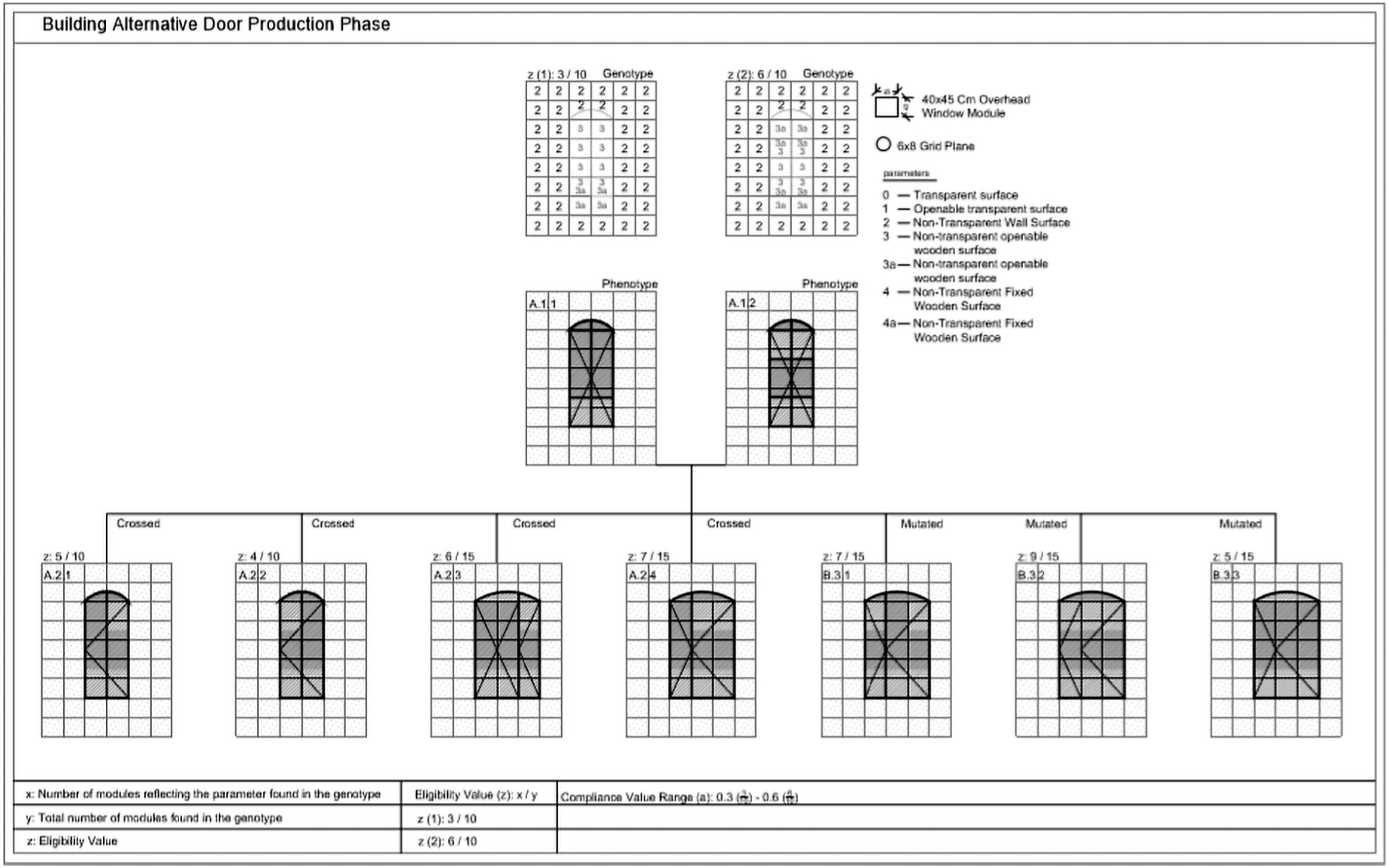
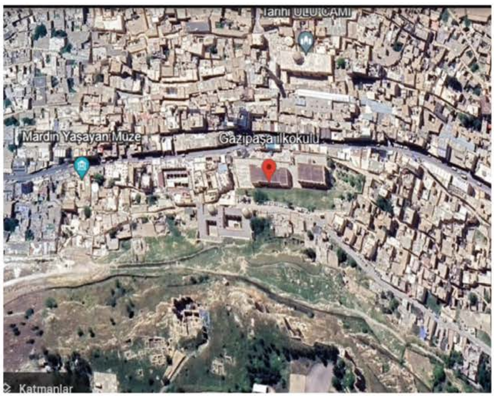

Building Alternative Door Production Phase
z (1): 3 / 10 Genotype
z (2): 6 / 10 Genotype
40x45 Cm Overhead Window Module
6x8 Grid Plane
parameters
0 — Transparent surface
1 — Openable transparent surface
2 — Non-Transparent Wall Surface
3 — Non-transparent openable wooden surface
3a — Non-transparent openable wooden surface
4 — Non-Transparent Fixed Wooden Surface
4a — Non-Transparent Fixed Wooden Surface
Phenotype
A.1 1
A.1 2
Crossed
Crossed
Crossed
Crossed
Mutated
Mutated
Mutated
z: 5 / 10
A.2 1
z: 4 / 10
A.2 2
z: 6 / 15
A.2 3
z: 7 / 15
A.2 4
z: 7 / 15
B.3 1
z: 9 / 15
B.3 2
z: 5 / 15
B.3 3
x: Number of modules reflecting the parameter found in the genotype
Eligibility Value (z): x / y
Compliance Value Range (a): 0.3 - 0.6
y: Total number of modules found in the genotype
z (1): 3 / 10
z: Eligibility Value
z (2): 6 / 10

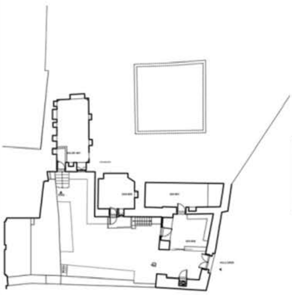
*Table 2. Identification data regarding the Gazipaşa school building*

| | ADDRESS: GAZİPAŞA SCHOOL BUILDINGS |
|---|---|
| | <br>Location on the map<br><br>Map data ©2024 Google |
| **IMAGES** |   <br>Images |

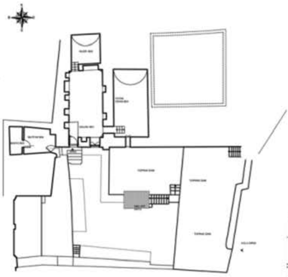
**IMAGES**

1910s [31]

**PLANS**



Ground floor plan



First floor plan

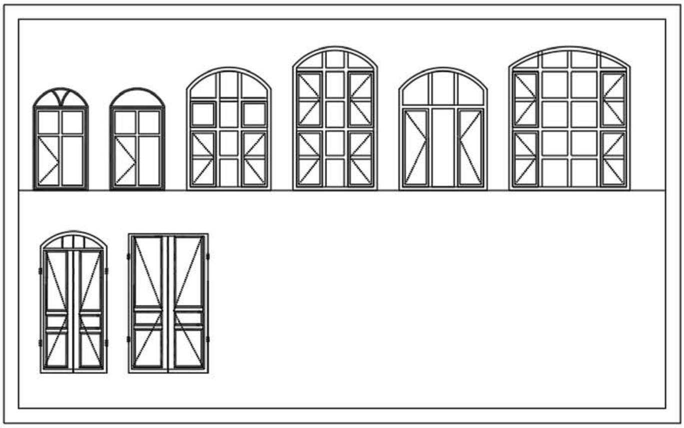
Second floor plan

Third floor plan

Fourth floor plan

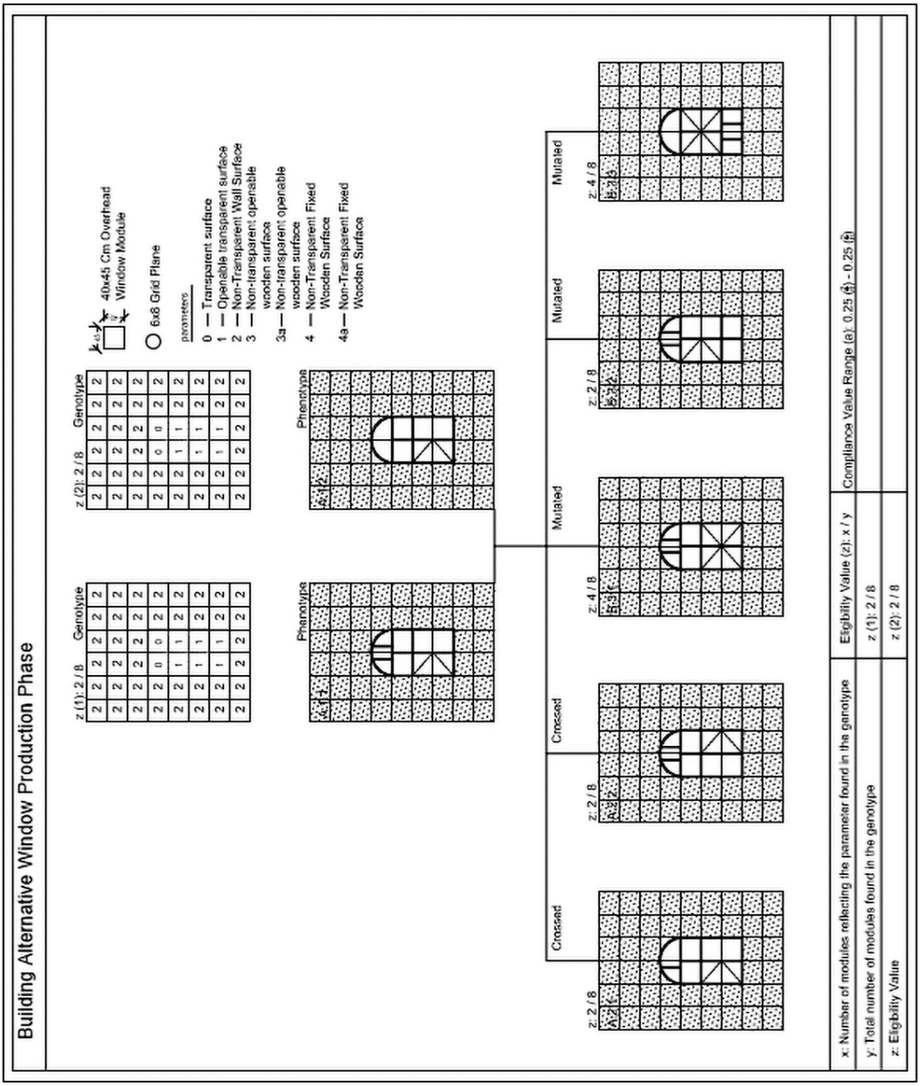
**SECTIONS**

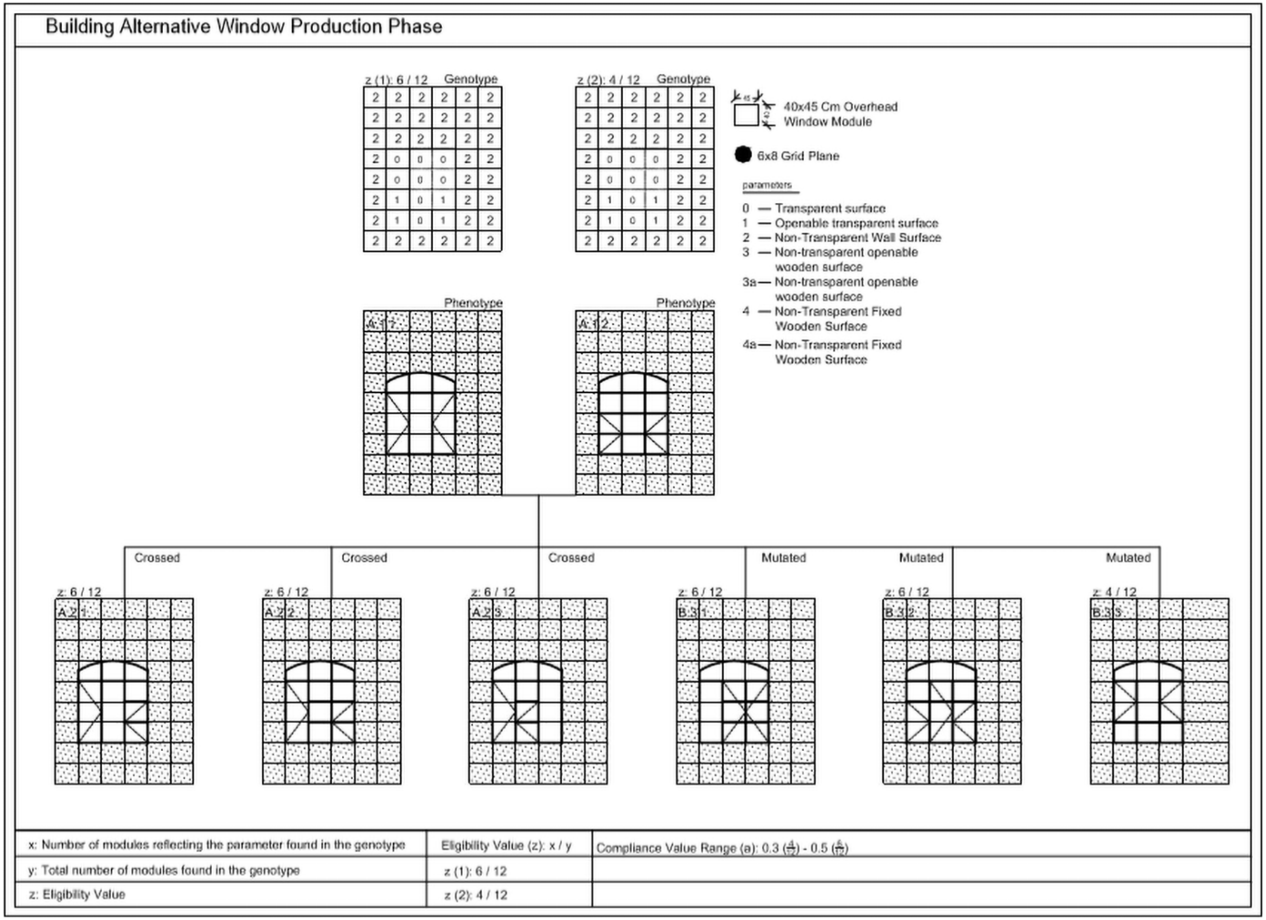
Section (Mardin Cultural Heritage Conservation Regional Board Archive)

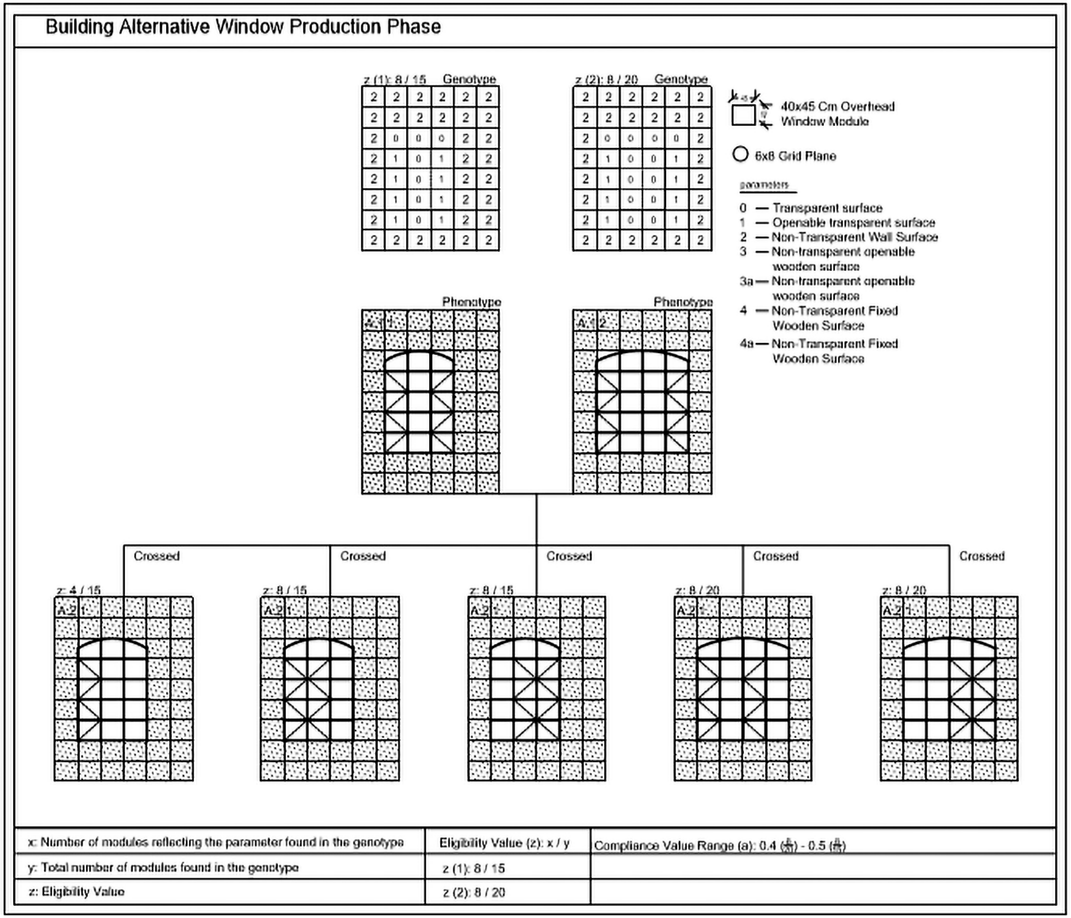


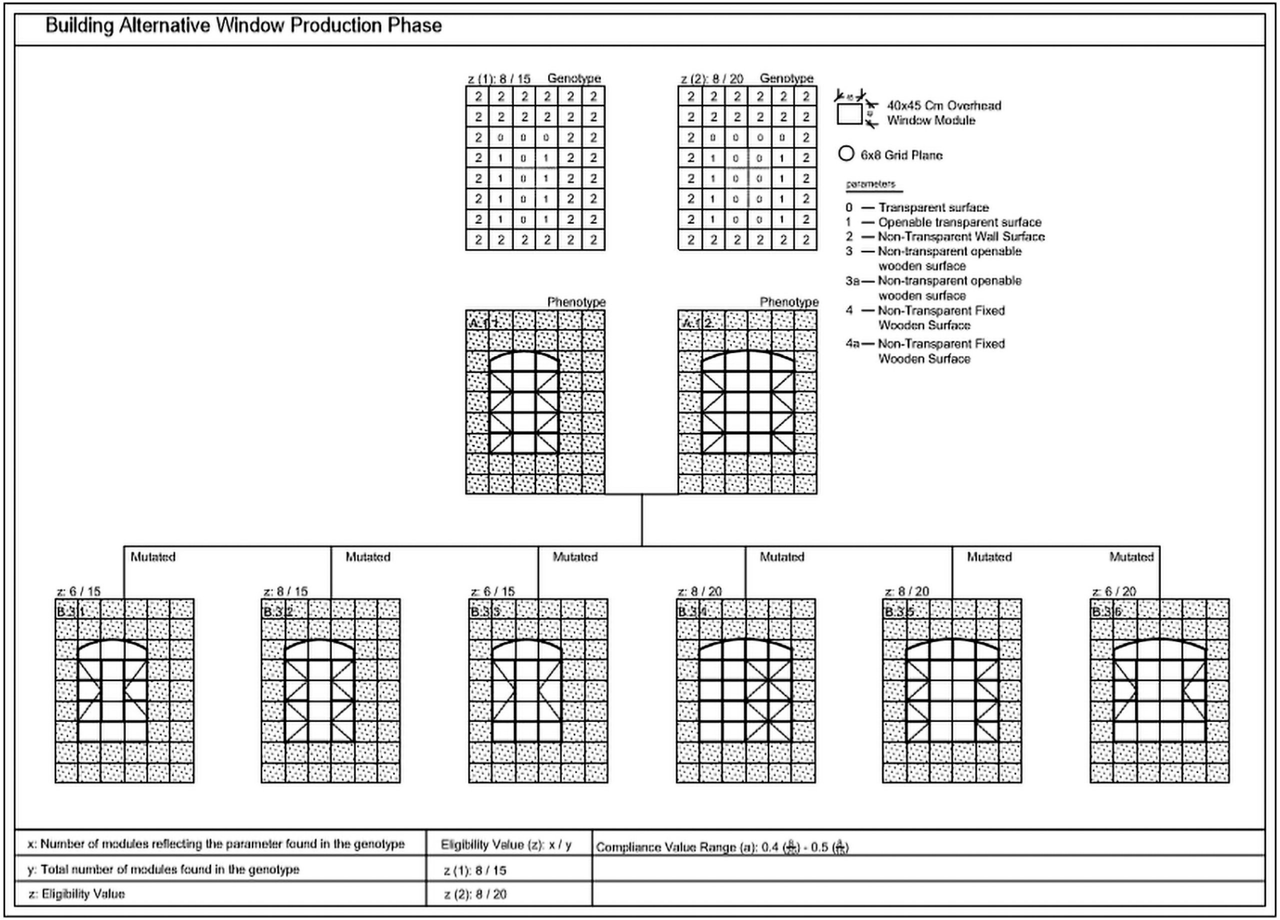
Examined frame types

As a result of the cross-referencing carried out for Gazipaşa School, 18 new typologies for windows and 4 new typologies for doors are shown in Figure 20.




Building Alternative Window Production Phase
z (1): 6 / 12 Genotype
z (2): 4 / 12 Genotype
40x45 Cm Overhead Window Module
6x8 Grid Plane
parameters
0 — Transparent surface
1 — Openable transparent surface
2 — Non-Transparent Wall Surface
3 — Non-transparent openable wooden surface
3a — Non-transparent openable wooden surface
4 — Non-Transparent Fixed Wooden Surface
4a — Non-Transparent Fixed Wooden Surface
Phenotype
Phenotype
Crossed
Crossed
Crossed
Mutated
Mutated
Mutated
z: 6 / 12
z: 6 / 12
z: 6 / 12
z: 6 / 12
z: 6 / 12
z: 4 / 12
x: Number of modules reflecting the parameter found in the genotype
y: Total number of modules found in the genotype
z: Eligibility Value
Eligibility Value (z): x / y
z (1): 6 / 12
z (2): 4 / 12
Compliance Value Range (a): 0.3 (4/12) - 0.5 (6/12)


Building Alternative Window Production Phase
z (1): 8 / 15 Genotype
z (2): 8 / 20 Genotype
40x45 Cm Overhead Window Module
6x8 Grid Plane
parameters
0 — Transparent surface
1 — Openable transparent surface
2 — Non-Transparent Wall Surface
3 — Non-transparent openable wooden surface
3a — Non-transparent openable wooden surface
4 — Non-Transparent Fixed Wooden Surface
4a — Non-Transparent Fixed Wooden Surface
Phenotype
Phenotype
Crossed
Crossed
Crossed
Crossed
Crossed
z: 4 / 15
z: 8 / 15
z: 8 / 15
z: 8 / 20
z: 8 / 20
x: Number of modules reflecting the parameter found in the genotype
y: Total number of modules found in the genotype
z: Eligibility Value
Eligibility Value (z): x / y
z (1): 8 / 15
z (2): 8 / 20
Compliance Value Range (a): 0.4 - 0.5


Building Alternative Window Production Phase
z (1): 8 / 15 Genotype
2 2 2 2 2 2
2 2 2 2 2 2
2 0 0 0 2 2
2 1 0 1 2 2
2 1 0 1 2 2
2 1 0 1 2 2
2 1 0 1 2 2
2 2 2 2 2 2
z (2): 8 / 20 Genotype
2 2 2 2 2 2
2 2 2 2 2 2
2 0 0 0 0 2
2 1 0 0 1 2
2 1 0 0 1 2
2 1 0 0 1 2
2 1 0 0 1 2
2 2 2 2 2 2
40x45 Cm Overhead Window Module
6x8 Grid Plane
parameters
0 — Transparent surface
1 — Openable transparent surface
2 — Non-Transparent Wall Surface
3 — Non-transparent openable wooden surface
3a — Non-transparent openable wooden surface
4 — Non-Transparent Fixed Wooden Surface
4a — Non-Transparent Fixed Wooden Surface
Phenotype
A.1.1
Phenotype
A.1.2
Mutated
z: 6 / 15
B.3.1
z: 8 / 15
B.3.2
z: 6 / 15
B.3.3
z: 8 / 20
B.3.4
z: 8 / 20
B.3.5
z: 6 / 20
B.3.6
x: Number of modules reflecting the parameter found in the genotype
y: Total number of modules found in the genotype
z: Eligibility Value
Eligibility Value (z): x / y
z (1): 8 / 15
z (2): 8 / 20
Compliance Value Range (a): 0.4 - 0.5

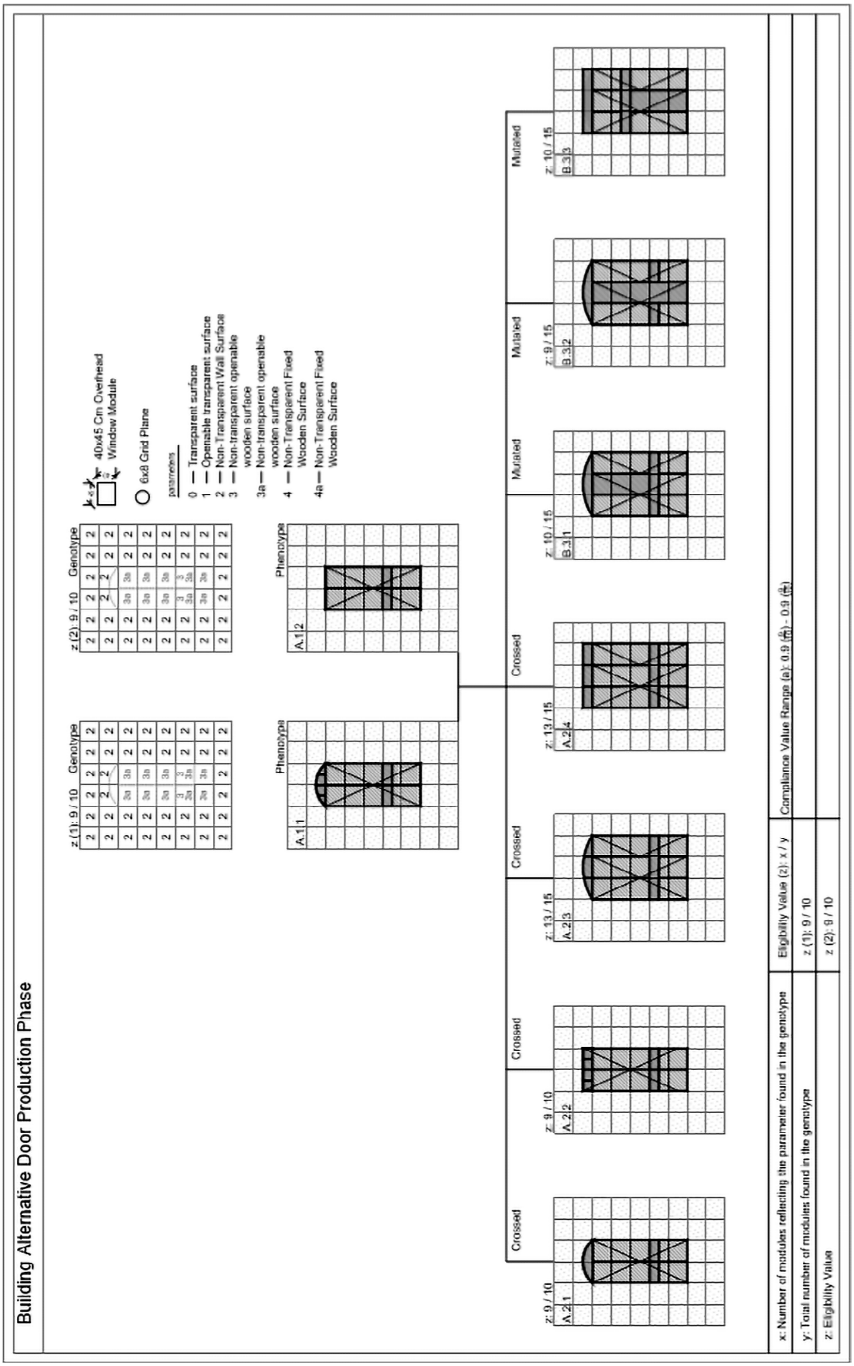



*Figure 20. Generated door and window typologies using genetic algorithms.*

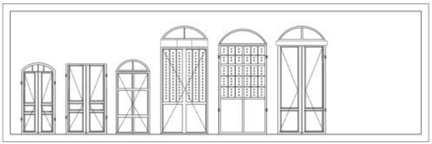
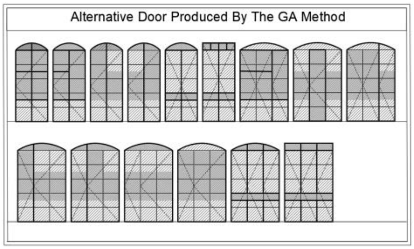
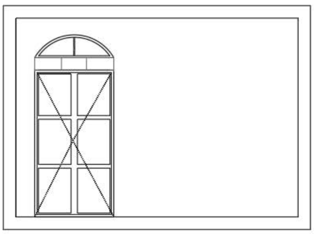
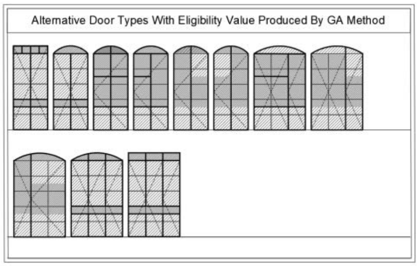
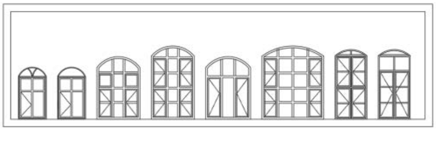
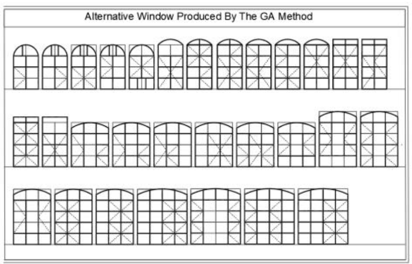
## 4. Results and conclusions

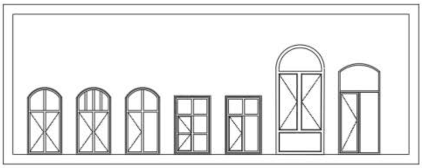
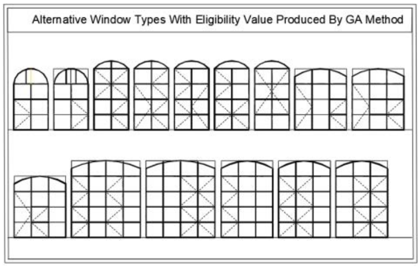
In the field of design, evolutionary computation methods have become increasingly prominent in recent years. Today, evolutionary design is a promising approach among computer-aided design methodologies. Genetic algorithms, a type of evolutionary design system, solve problems by subjecting them to an evolutionary process. Studies that traditionally take a long time to analyze can be completed in a short time using genetic algorithm methods and aim to achieve the best possible solution in all stages of the problem by performing operations such as selection, crossover, and mutation on existing solutions. While genetic algorithms do not always guarantee finding the optimal solution, they can provide reasonable results in short periods for such problems. Through the logic of genetic algorithms, designers can consider the requirements of their desired architectural design from the outset. The resulting product's requirements and constraints help narrow down the solution space, allowing the process to proceed with the most suitable solutions to achieve the desired outcome. The study presents an integrated generative design system after analyzing the characteristics of productive design systems, utilizing genetic algorithms and shape grammar at different stages. However, predominantly focusing on understanding how genetic algorithms can be utilized in architectural design, an exemplary study was prepared. The study evaluates the typologies of doors and windows belonging to historical structures such as Mardin High School and Gazipaşa Primary School. Rules and suitability functions were established for selected joinery typologies, resulting in diverse door and window typologies for residential buildings. The study identified a total of 6 different door typologies and 8 different window typologies for the examined structures. Using the genetic algorithm method, crossbreeding and mutation processes were applied to these joinery typologies, resulting in 15 different door typologies and 30 different window typologies that meet suitability criteria. These findings facilitate the integration of alternative typologies into new designs by enabling the use of local data in the doors and windows of buildings planned for historical contexts. Moreover, this approach holds significant promise for creating alternative facade typologies. The study demonstrates that the preparation of suitable joinery typologies in terms of conservation interventions for historical structures with original values is facilitated by producing alternative typologies. Based on the data obtained in this study, various conclusions have been reached and are as follows:

- It is believed that designers will further develop by changing their perspectives on computer-based productive systems to view computers as design generators.
- Approaches towards conservation interventions such as restoration and reuse can utilize genetic suitability functions in the architectural design process for generating new door and window typologies.
- The contribution of genetic algorithms as an optimization tool in the design field has been highlighted.
- Future studies can define facade typologies that are designed and planned in advance.
- This approach can be applied in future research to develop facade typologies with various architectural styles.
- It can be selected for buildings with complex system relationships, considering factors like suitability functions.
- Ensuring optimal conditions for the evolutionary production process will contribute to achieving superior results.

Furthermore, some outputs of genetic algorithms (GA), especially in areas such as design and aesthetics, may be based on subjective evaluations rather than parametric measurements. Data comparing original and non-original typologies found in historical buildings created by genetic algorithms are presented in Table 3.

*Table 3. Different door and window typologies in Mardin and alternative doors and windows generated using a genetic algorithm (GA) method*

| **Door and window typologies of the analyzed buildings** | **Door and window typologies produced by GA method** |
|---|---|
| Door typologies of the analyzed buildings | Door typologies produced by GA method |
|  |   |
| Non-original door typologies of the analyzed buildings | Alternative door type with eligibiliy value produced by GA method |
|  |   |
| Window typologies of the analyzed buildings | Alternative window type with eligibiliy value produced by GA method |
|  |   |

| Non-original window typologies of the analyzed buildings | Alternative door type with eligibiliy value produced by GA method |
|---|---|
|  |   |

- Appropriateness of the solution approach: The subjective view may be whether the method followed captures the problem accurately.
- Applicability of the results to real life: Subjective opinion can be developed on the practical use of the result.
- User experience and functionality: Some results may be subjective when evaluating the functionality of designs in terms of user experience. For example, the way an architectural form makes people feel, the “behavioral appropriateness” or “comfort level” of a space may differ based on user comments or personal experiences. Although GA provides an optimal result in terms of functional and ergonomic aspects, how users experience these spaces is a subjective criterion.
- Cultural and social fit: The results presented by genetic algorithms can be subjectively evaluated in terms of “appropriateness” in a cultural or social context. For example, how a building form or surface texture is perceived by the local community or how well it fits with cultural heritage is based on subjective judgments, and the GA's technical measurements may not be able to fully assess these factors.
- Material selection and texture preferences: GA can provide optimization in the selection of appropriate material or surface texture for designs, but the “feel” quality of the texture or characteristics such as color, brightness, etc. are based on subjective evaluations. The aesthetic or tactile expectations of the designer or user are shaped by non-parametric, subjective preferences.
- Social interaction and psychological impact: The impact of space on human psychology and social interaction is also based on subjective evaluations. While the GA's spatial solution proposals are parametrically appropriate, the design's impact on human mood, psychological comfort or social connections can be evaluated through subjective interpretations.

Therefore, in cases where genetic algorithms offer parametric solutions, but subjective factors come into play in decision-making processes, expert or user experiences should be given importance. The data obtained supports the conclusion that genetic algorithms should be frequently and effectively utilized in architectural design applications. Particularly, the use of this method is recommended for creating facade typologies of structures located in different climatic regions. Through this method, the suitability of existing typologies for contemporary requirements can be evaluated based on specific criteria, thereby ensuring the sustainability of traditional architectural language. It is believed that traditional structures achieve a certain balance in their ratio of solid to void spaces on facades, and maintaining this balance is critical for the sustainability of architectural language. Therefore, it is recommended to comprehensively examine algorithms based on productive systems and generate new window and door typologies similar to this ratio.

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**Biographical notes**

**Mizgin Gökçe Salık** is an architect, academic and researcher with about eight years' experience.She is a lecturer at Ağrı İbrahim Çeçen University, Department of Architecture and Urbanism and a PhD graduate of Dicle University, Faculty of Architecture, Department of Architecture. She has worked on application projects and designs in the private sector and has published articles on computational design, ecology, sustainability and traditional architecture.

**Fatma Demet Aykal** has been working as an academician at Dicle University, Faculty of Architecture, Department of Architecture since 1990. In 2018, she was appointed professor. Her academic fields are algorithms in the re-functionalization of historical buildings, architectural forms and formations, environmental factors in architecture, ergonomics in architecture. Since 1992, Aykal has had 32 articles indexed, 45 papers and 9 book chapters published and has completed 2 research projects. Until today, she has supervised 25 master's theses and 5 doctoral theses. She continues her duty as the dean of the same faculty.

**Summary**

The genetic algorithm (GA) is inspired by natural selection, emphasizing the survival of the fittest. In GAs, data is encoded as genes, and optimal solutions are achieved through crossover and mutation operations on these genes. This study focuses on a key issue in re-functionalizing buildings, where facade elements designed without sustainability concerns become problematic. The design approaches for interventions in historic buildings remain a point of debate in architectural conservation and restoration. This study examines the facade changes due to functional transformations in a historic educational building, using GA as a generative system approach. The research specifically suggests new door and window typologies suited to the functionalization process of traditional buildings in historical settings. Genetic algorithms and shape grammar were the main methods employed. A field study applied GA to propose new door and window types with compatibility values. The analysis focused on a historical high school in Mardin (Turkey), generating alternative joinery designs. Thirty window and fifteen door typologies were developed, and while the original building's facade openings maintained their traditional form, some annex additions lacked conformity. It is thought that this study should be a methodology that can be used in the production of exterior joinery typologies in the additions or completions to be made in the process of re-functioning in many different cities, especially in the historical texture, to protect sustainability. It is believed that this approach will contribute significantly to conservation efforts in cultural heritage buildings, offering a reference for restoration practices.

**Riassunto**

L'algoritmo genetico (AG) si ispira alla selezione naturale, enfatizzando la sopravvivenza del più adatto. Negli AG, i dati sono codificati come geni e le soluzioni ottimali vengono raggiunte attraverso operazioni di crossover e mutazione su questi geni. Questo studio si concentra su una questione chiave nella rifunzionalizzazione degli edifici, dove gli elementi di facciata progettati senza preoccupazioni di sostenibilità diventano problematici. Gli approcci progettuali per gli interventi negli edifici storici rimangono un punto di dibattito nella conservazione e nel restauro architettonico. Questo studio esamina le modifiche della facciata dovute alle trasformazioni funzionali in un edificio scolastico storico, utilizzando l'AG come approccio di sistema generativo. La ricerca suggerisce specificamente nuove tipologie di porte e finestre adatte al processo di funzionalizzazione di edifici tradizionali in contesti storici. Algoritmi genetici e grammatiche di forma sono stati i principali metodi impiegati. Uno studio sul campo ha applicato l'AG per proporre nuove applicazioni.