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PRODUCTION OF THREE-DIMENSIONAL FORM ALTERNATIVES FROM ICONIC BUILDING PLANS IN PARAMETRIC DESIGN ENVIRONMENT

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Abstract

Nowadays, the development of technology and thus, the resulting digital architecture concept has brought the search for originality and form in design to the agenda of designer. The ability to produce forms in computer technologies and the applicability of these forms in building production has been effective on these search. However, functionality is not the priority for the sense of form and functionalizing these forms subsequently results in problems. In these forms, it has been observed that function types of abstract compositions are obtained, and the connection between form and function types remains weak. For this purpose, it will be useful to start with iconic building typologies adapted to formal layouts. Functional templates should be addressed as a starting point, and depending on this fundamental input, form alternatives should be sought. Within the scope of this study, it is aimed to investigate the functionally and formally tested and used iconic schemes in modern period, by producing the alternatives that derive from these fundamentally experimented forms in computer environment. Within this context, the study covers the process of obtaining three dimensional form alternatives in a short time period including not only functional properties but but also meeting current visual expectations and consequently proposing new methods for architectural applications.

1. INTRODUCTION

Contrary to design methods that are being used for centuries, forms produced in computer environment can be created with different derivation methods. With this method, the designer has the opportunity to choose the form he will develop among the possibilities. Thus, the computer has become a digital design environment guiding design in which all stages can be fed back, instead of a tool merely used to convey and transfer what has been designed. Architects who think of the computer as a design environment approach the design process with a new perspective and try to maintain continuity from the thinking process to the final product. The ability of computers to organize, calculate, store, etc., can be advantageous in directing the first stages of design. In addition, computer technologies offer architects new design areas by providing easy application of complex architectural forms, which until now have been very difficult to design and apply.

Parametric design, algorithmic design, etc. sub-research areas have been studied on the use of computer technology for design development. At the beginning of the architectural production process, the evaluation and regulation of the numerical data obtained as a result of observing the rules reveals the parametric approach. This system is a successful computer aided design system that will allow multiple results to be generated if the obtained data is changed. In this sense, even if the design is curvilinear and variable, all the mathematical data of the product is under the control of the designer.

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Architectural adaptation of three-dimensional technology has enabled the possibility of a unique design environment that can be previously predicted or easily transformed. The creation of 3D models by using computer technology facilitates the perception on design, and provides the convenience for going back and making corrections in case of errors or idea changes. Thanks to the fast and simulable structure of this environment, design alternatives increase, and an environment for producing and transferring these design alternatives in a rapid manner can be created. Moreover, thanks to the digital fabrication system in the application phase, easier, faster and error free production is possible.

Nowadays, with the efforts to be unique in architectural design and the consequently increasing search for alternative forms, the production of new forms and the applicability of these forms in the production of structures with support from computer technologies have been influential. The aim of this study is to produce alternatives in a computer environment that respond to functional requirements with reference to modernist – iconic building schemes formed based on the functional templates, but derive from these fundamentally tried shapes as a form. Functional templates are considered as starting points, and alternatives based on these basic inputs are sought.

2. DESIGN PROCESS AND ARCHITECTURAL FORM

Architectural form is the specific statement of conditions. Form is created as these conditions, which consist of requirements, conditions of use, client desires, constraints, and so on, are intersected in the mind of the designer [6]. The design process has a significant impact in the creation of form. In this section of the study, the steps and methods of design followed for the completion of a design product, the psychological process, the different approaches, and the opinions of the researchers working within the design process will be included. In addition, architectural form formation, designer decisions and restraints during this process based on the aim of design will be discussed.

The phenomenon of design, which is used in many fields and constitutes the foundation of architecture, is defined as “Creating, generating something that did not exist before, aimed at a specific purpose, in a way that is compatible with the reality” [8]. Design can be thought of as the beginning of an analysis action towards the solution of a problem or generated by a necessity. The concept of design consists of the creation of these action processes under appropriate conditions while taking knowledge and experience into consideration.

The design process, as a structure, has a complex system rather than being a simple action set. This process is included in the complex system group because the design problem, functional requirements and restraints cannot be precisely defined. In addition, the areas of interest and actors effective in the progression of the process taking up a lot of space, and the starting point not being precisely determined demonstrates the complexity of the process [3]. The solution of the problem is the emergence of the designer's perception of the problem, and in any phase a definite end may not be achieved. As the design progresses, the designer can make new changes and offer different solution suggestions. This leads to the redefinition of the solution and the problem.

Evaluating the thought structure of the designer, İnceoğlu (2004) stated that “Design solutions are sometimes realized through logical processes based on reasoning and analytics, and are often transformed into form according to the designers’ creativity, knowledge and experience” [4]. As can be understood from this perspective, the design process can also be intuitive as well as analytical, depending on the designer’s preference. However, the complexity of the design process, the uncertainty of the results, created the need for a systematic structure in the control and routing points. This necessity has led to the structure of algorithmic thinking in the solution of complex systems.

Algorithmic thinking is based on an approach where structurally complex problems are separated into parts, and these parts are organized according to regular processes. Solution of a problem separated into smaller parts by using simple processes is more likely. These parts are handled, and their places within the whole are determined and they are accordingly located [2]. If we think that architectural design consists of a multi-tiered process, the use of algorithms in architectural design will make the design process more systematic and obtaining a result in problem solving will become a regular and operational process.

Within a systematic design process considered as a problem-solving method, the designer must define the strategic decisions for the purpose of the result he or she wishes to achieve and the path he or she wishes to follow during the process. Geometrical and organic structure approaches are taken into consideration in order to make form decisions in a structure that contains upper and lower system relations as a design product [9].

A geometric structure is a structure approach where a building takes its form using regular geometric forms. In architecture, the sub-elements of the building are selected in prime geometric forms, and alternatives in various forms can be derived. On the buildings, prime geometric forms such as rectangle, square, triangle, circle, sphere, and cylinder are used in various forms [10].

On the other hand, an organic structure can be defined as form created by groups appropriate to the purpose of the building, created by the organized unification of pieces that complete each other, where each functional piece is considered as an organism element. In this approach, geometric forms can be used as well as deformed forms [10].

Figure 1. *From left to right, Louvre Pyramid, Paris (Geometric) Ordos Museum, MAD Architects (Organic)*

In architectural forming, the starting points are chosen according to the clarity of the data in solving different design problems. These may be starting points that provide functional or formal weight to the structure, such as deductive, inductive approaches, and geometric, organic structures. Regardless of which choice is selected to continue the process, the first step in providing data for design is to define the functionality of the structure as sub-sets. For this reason, the functional organization of the structure, defining the relationships between closely related parts and dividing them into sub-functional groups is a preliminary study for the formalization stages in the design process [10].

When we deal with typological plan geometries as functional constructions, it can be seen that circulation is linear or loop-like. When these types of planning are examined, if there is no loop between functional relations, it is seen that the plan types are in linear geometrical structure, and if it contains a loop, courtyard and organic forms are seen in a way that can respond to the loop.

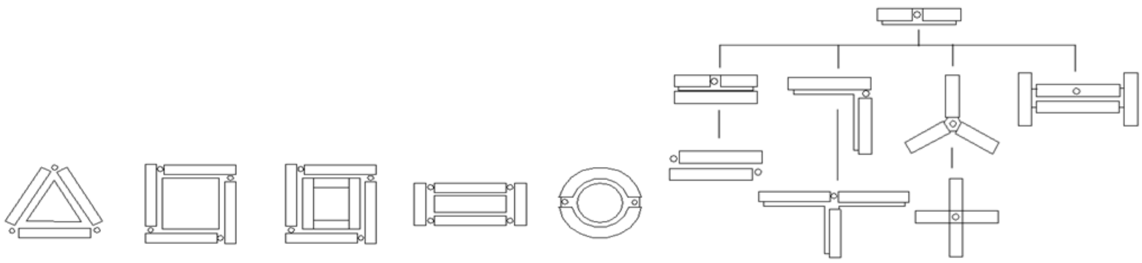

Figure 2. Building forms containing loops in their functional structure, linear – tree structure building forms [11]

3. THE EFFECTS OF COMPUTER-BASED DESIGN ON CURRENT FORM APPROACHES IN ARCHITECTURE

Along with the developing technology, digital techniques have provided great advantages to designers in design process and application phase. The ease of transferring forms created in the mind to a digital environment, and even the creation of a design environment in which the beginning and development stages of design can be executed, has led to radical changes in architectural forming. The numerical, algorithmic structure and integration of computer-aided tools to architectural design has brought about the complexity of geometry in constructions and the ability of easily overcoming this complexity. The digital design concept that emerged with the development of computer techniques makes use of the computer's operational techniques. The reflection of this technological innovation to architecture creates different design approaches. One of these approaches is parametric design, which we will discuss in detail.

Parametric design can be thought of as a form of design thinking enhanced with computation. It applies a design method based on specified parameters. In this method, instead of drawing lines, a design organization is formed by defining parameters.

Parametric design, an alternative tool for modeling complex forms, emerges as a unique and distinctive design model. In this regard, the development and reformulation of existing tools and applications has begun to affect forms. With the reorganization processes in the parametric system, process models of digital design adapt to changing content [5].

According to Aish and Woodbury, “nothing can be created in a parametric system for which a designer has not explicitly externalised. This runs counter to the often-deliberate cultivation of ambiguity that appears to be part of the healthy design process” [12]. For this reason, the use of digital software has become inevitable for the clear expression of the parametric system.

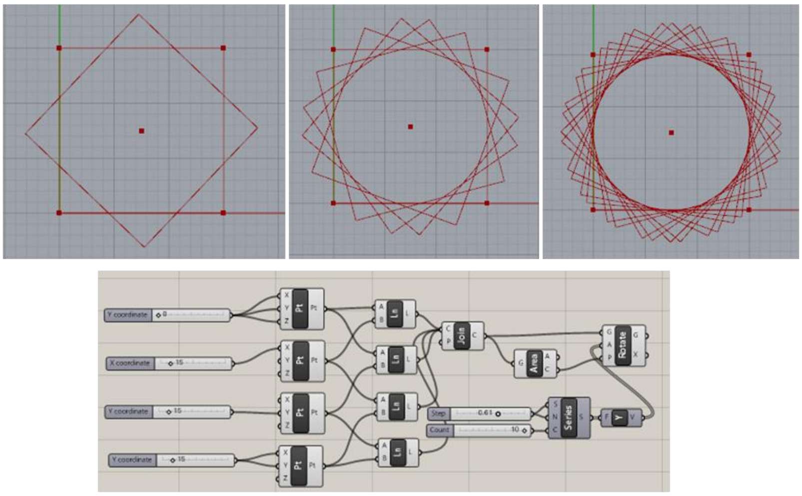

Figure 3. *Two dimensional parameterization of a simple geometric shape in a digital design environment*

Changes in design are an essential part of the design process while searching for solutions to design problems. The design variants support the development of the design, which enhances the quality of the design works. For this reason, the designers are in constant search for different alternatives in the universe of possible solutions. In computer aided design (CAD), which designers often refer to, the demand for flexible tools has increased over time. Parametric design has become one of the important sources of computer aided architectural design (CAAD) over time due to its advantages such as its diversity in the design process and the increase of process efficiency [1].

In parametric modeling, software applications such as Rhino (Grasshopper), 3ds Max, Dynamo (Autodesk), and Generative Components (Bentley) often provide a quick way to discover complex ideas beyond traditional techniques such as creating a physical model with hand drawing. These computer programs are cognitive tools that define the steps of design development as well as design production, and constitute the final step of digital shaping.

Designers who have broadened their perspectives together with the computer-aided design environment have sought new forms and have preferred methods with richer qualities in the search for physical forms. It is seen that with the broad transformation of design that has changed in every direction, different alternatives are sought during the process instead of typological and static approaches, and curvilinear surfaces and complex forms are becoming influential in shaping these alternatives [7]. Thus, original masses have begun to be produced by going beyond known building types.

In these searches for form, form editing steps are used to create the final form from computer software commands. These steps take place as commands in all CAD software, and they are used consecutively, depending on the designer's formative approach. There are distinct geometric characteristics seen in formative approaches that evolve with digital environment, and in the forms obtained. We can list these characteristics as follows.

Geometric characteristics of current formatting approaches in building design:

1- Curvilinear bending of plane and removal of part from curvilinear surface (Horizontal and Vertical)
2- Deformation of prime Euclidean forms (Bending, changing angles)
3- Obtaining new forms by adding and subtracting from prime Euclidean (Boolean Operations)

We can give the following examples within the formatting approaches to form alternatives that go beyond traditional modeling boundaries in time and into a systematic formation .

Figure 4. *Respectively, Curvilinear bending of plane and removal of part from curvilinear (Rolex Learning Center, SANAA), Deformation of prime Euclidean forms (Denver Art Museum, Daniel Libeskind) Obtaining new forms by adding and subtracting from prime Euclidean (Opus Building, Zaha Hadid)*

With this wide range of transformation of design that changes every direction, it is seen that different alternatives have been used instead of typological and static approaches in the process stage and curvilinear surfaces, complex forms have been influential in shaping these alternatives [7].

4. GENERATING FORM ALTERNATIVES WITH MODERNIST TYPOLOGIES IN COMPUTER ENVIRONMENT

Variations of a design idea are an uninterrupted and repetitive search process, and there is a high probability that a previously abandoned solution will be revisited to re-process it. The tendency to differentiate in this age of developing technology has become an important factor in current architectural design. The designers have been moving towards structures which are designed with a thinking strategy of higher aesthetic power rather than functional power in the way of differentiation in architecture. In these formations there is a benefit of diversification of the typological system by the designers in cases where the function types are weak. In this regard, functional forms can be considered as the starting point and form alternatives based on base inputs can be sought. Thus, it may be possible to obtain a compatibility of form and function in the alternatives sought by looking at iconic templates.

In this section, form alternatives will be obtained by using typological schemes through the formation shapes we have classified. Effective parameters play an important role in the formation process. At this stage, contrary to the traditional architectural composition processes, in the parametric design environment, controlled models will be created with form variations. Considering parametric design as a general procedure, the use of design variables of a parametric model is seen as a methodology that enhances design competence. The geometric systems to be used in the study include diversified discovery-based strategies of formal, productive design.

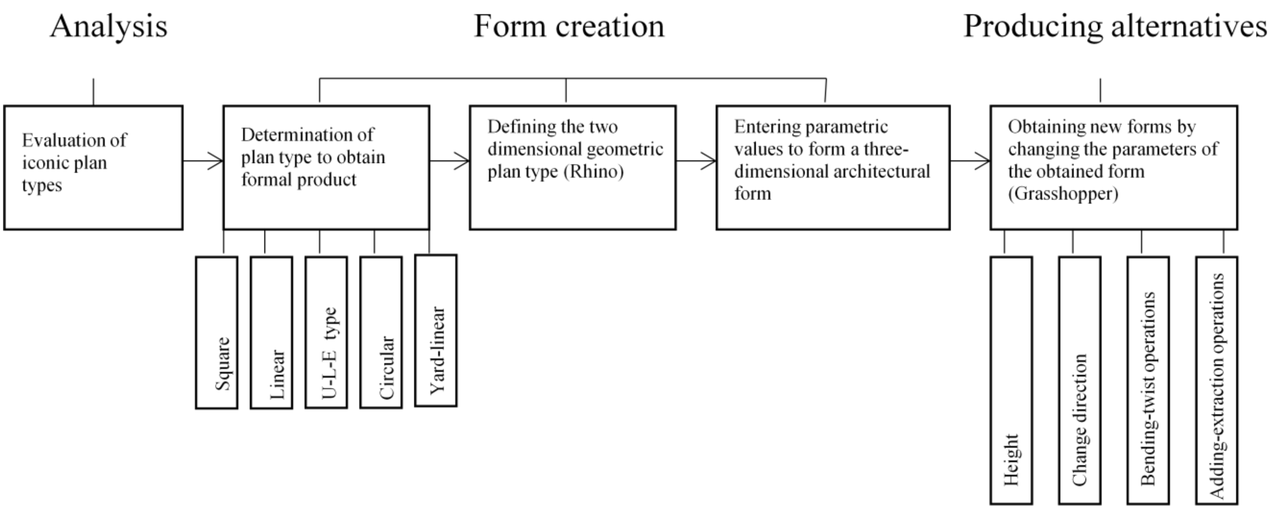

Figure 5. Process steps of producing form alternatives

The phases of form generation will be discussed through the geometric change operations of the formatting approaches. Form generations and derivations of alternatives will be discussed under the three headings we have described in the fourth section. In this design process, firstly the iconic plan schemes will be mentioned and a preliminary evaluation will be made, and type plans will be selected to generate the formal product. The plan type parameters defined in the computer aided environment and selected in accordance with the formatting approach through these types will be determined. These parameters, which consist of determined points of the two dimensional model created in the digital environment, give point values of the form such as height, width, geometry breaks or folds. The iconic masses forming the three-dimensional model consist of width, length, height and surface parameters. In the last step, alternate forms will be produced by deformation processes such as horizontal and vertical direction change, surface bending, bending movements, object addition and subtraction operations on the produced model.

The plan types considered with an iconic approach, which is a formation principle created by grouping the morphological similarities of the structures studied from the past to the present as a result of academic studies, will form the basis of this study. In this study, typological plan geometries to be determined as inputs in the design process will be discussed.

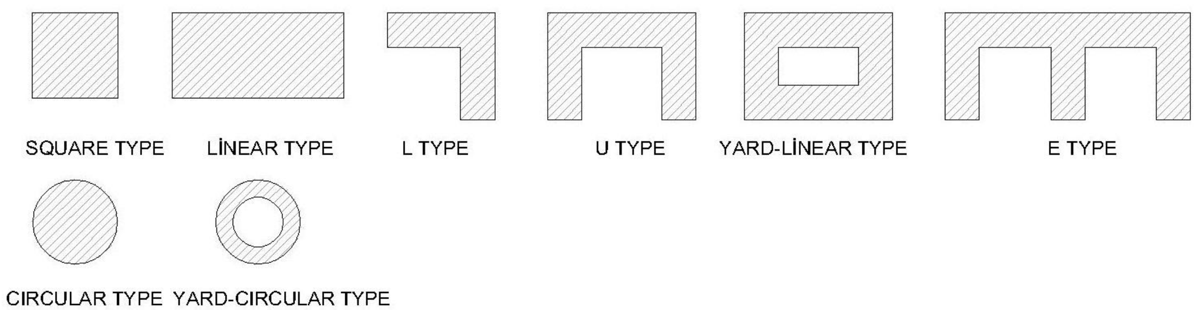

Figure 6. *Typological plan schemes to be used in form generation*

4.1. Derivation of Form Alternatives in Parametric Environment: Horizontal Curvilinear Bending Of The Plane and Removing Parts from a Curved Surface

In this section, alternative forms will be studied in the Grasshopper environment to types where surfaces are curvilinearly bent in the horizontal and vertical planes, which is one of the geometric characteristics of current formatting approaches. The type plans we will study these alternatives with are rectangular and U type schemes.

The software tool to be used in the applications tracks the change of the parametric models in the computer application when a parameter is changed, and shows the historical change of the model, thereby allowing the designer to revert back to an earlier design stage, and apply the changes, therefore having a broader scope of control and instantly receiving feedback. These changes mean that there is chain of dependencies, that is, a designer can switch to any stage, change the value of the parameters, and rebuild the model. The changes in the parametric model structure the model according to the new values and the designer evaluates whether the reconstructed or changed parameters will cause any problems in the solution.

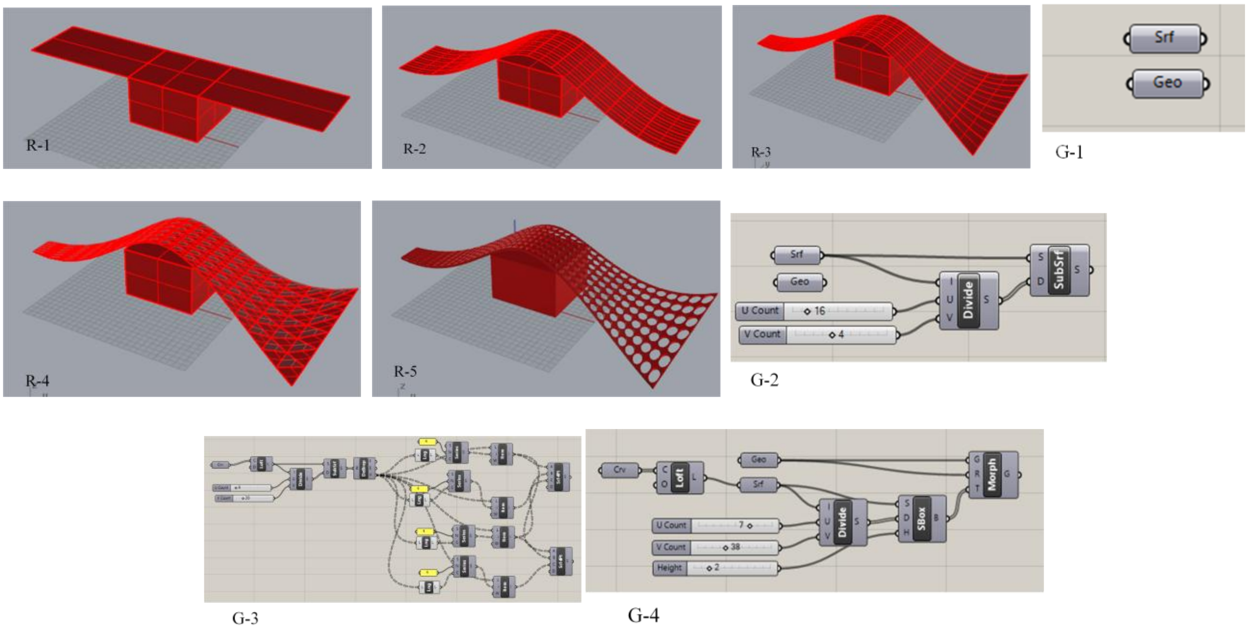

Figure 7. Horizontal curvilinear bending of the plane and removal of part from the surface model-1

The procedure of parametric system creation in design begins with the identification of geometric components (Figure 7, R-1). Here, a simple rectangular geometric scheme is chosen as a type plan. The geometric surface defined in the Grasshopper interface is firstly twisted in the z-axis to obtain a wavy form (Fig. 7, R-2). In this model, the parameters of the plane are the direction, length, angle of the slope of the plate. It is possible to change the parameters in the model created with this system. In the trials for alternatives, a new form was obtained with a roof cover, the length of which was changed on the Y-Z axis (Figure 7, R-3). The cover can be divided into pieces considering the application factor (Figure 7, R-4). These parts can be made with the system of triangular or double-curved surfaces which we mentioned in digital production. Moreover, multiple formatting approaches can be used in a model. At the same time, addition and subtraction operations can be performed on the horizontally curved layer (Figure 7, R-5). In addition to the parameters of the curving processes, the parameters of R-5 may be measures of the geometric shape subtracted, the number, regular or scattered sequence movements, and the fineness or thickness ratio of the plate.

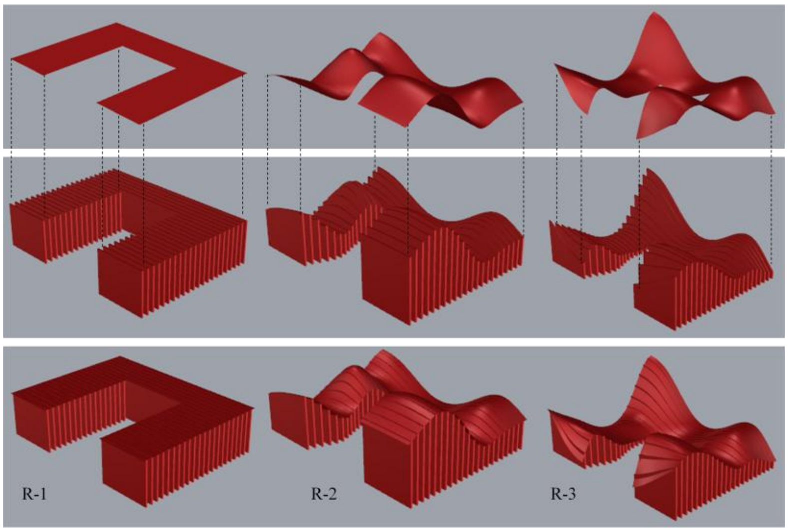

Figure 8. *Horizontal curvilinear bending of the plane and removal of part from the curvilinear surface model-2*

4.2. Derivation of Form Alternatives in Parametric Environment: Deformation of Prime Euclidean Forms

In this section, design samples will be obtained by manipulating the variables that are corner coordinate values, length, height, and horizontal and vertical angles or bends. As a result of the changes made in the parametric model, a design group will be created and the geometry changes will be allowed without any situations such as going back and deleting the models. The alternatives will be carried out in the form of square type, tree-form E type and circular type that are selected from iconic plan schemes, and via the stages and forms of the deformation procedures of these types.

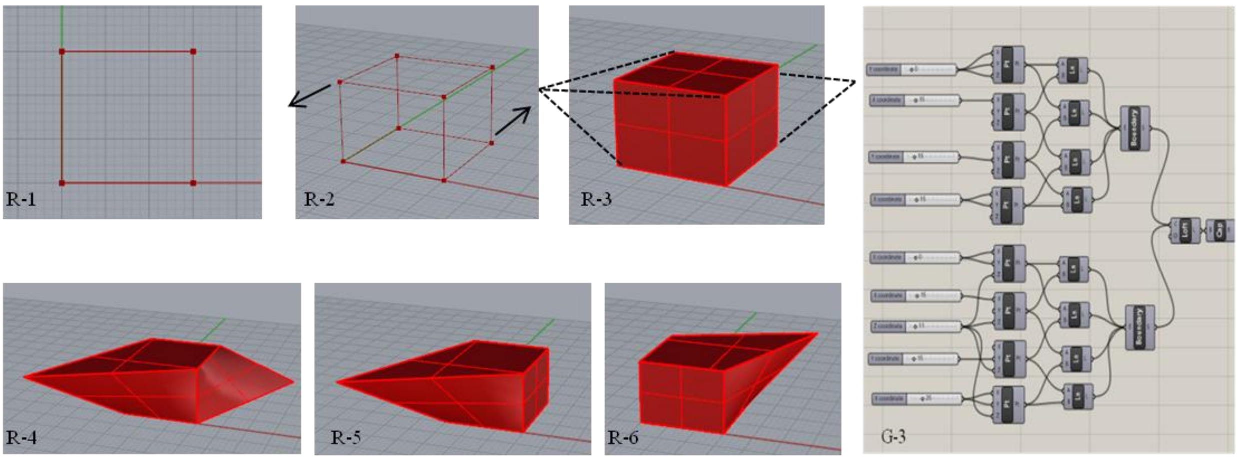

Figure 9. *Alternative form generation by deformation of prime Euclidean forms, model-1*

In the first model, a square scheme was used from linear plan types. The movement of the axes is the primary focus of this model. The points in the model are among the basic elements of the organization provided for the formation of geometries in parametric design. These reference points identify the starting line and connecting elements of the geometry to be obtained (Figure 9, R-1, G-1). The points of the geometric shape with corner coordinates given in two dimensions are determined. The parameters of these points vary in the X and Y axis (Figure 9, G-1). The geometric shape elevated in the Z-axis becomes prismatic in the third dimension (Figure 9, R-2, G-2). In order to obtain the required data for parametric element design applications with variables, a combination of various components is provided

(Figure 9, G-2). In the deformation of this model, the point variables can be moved in X, Y and Z coordinates (Figure 9, R-3).

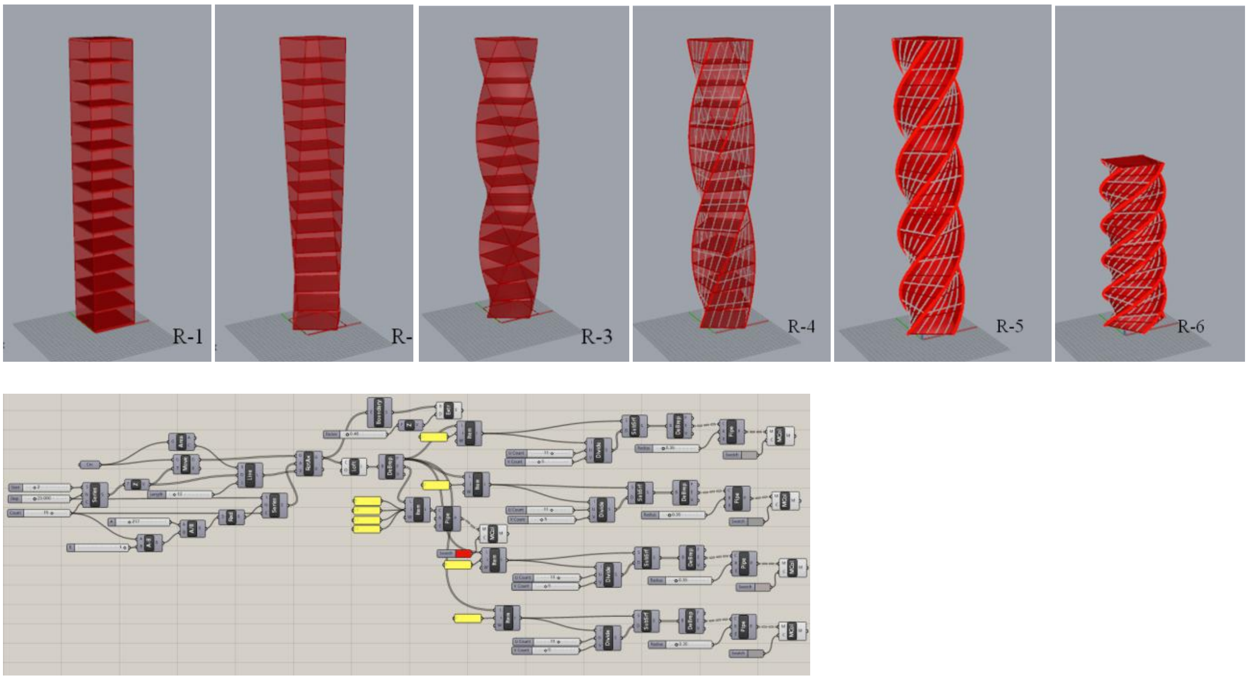

Figure 10. Alternative form generation by deformation of prime Euclidean forms, model-2

In the case of deforming prime Euclidean forms, the second formative approach is obtained by vertical bending movements. In this model, the square form plan type will be used. The plan chart created on the ground represents the desired floor area. This scheme, which may be the main line of any form, consists of variable numerical values in X and Y directions. To create the simple line of the form, the "move" command creates a mass with a component in the Z direction. The resulting prismatic model is the expression of the iconic plan type in the third dimension (Figure 10, R-1, G-1). The parameters of this model are the aspect ratio, the height, the number of floors and the distances between the floors (Figure 10, G-1). The mass created in the next step is formed by rotating around the axis based on the center line (Figure 10, R-2, G-2). The organization of the components provides a proportional flow between the floors. The parameters describe the angle of rotation of each floor with numerical values. By continuing these processes, the bending rate can be tightened and expanded (Figure 10, R-3).

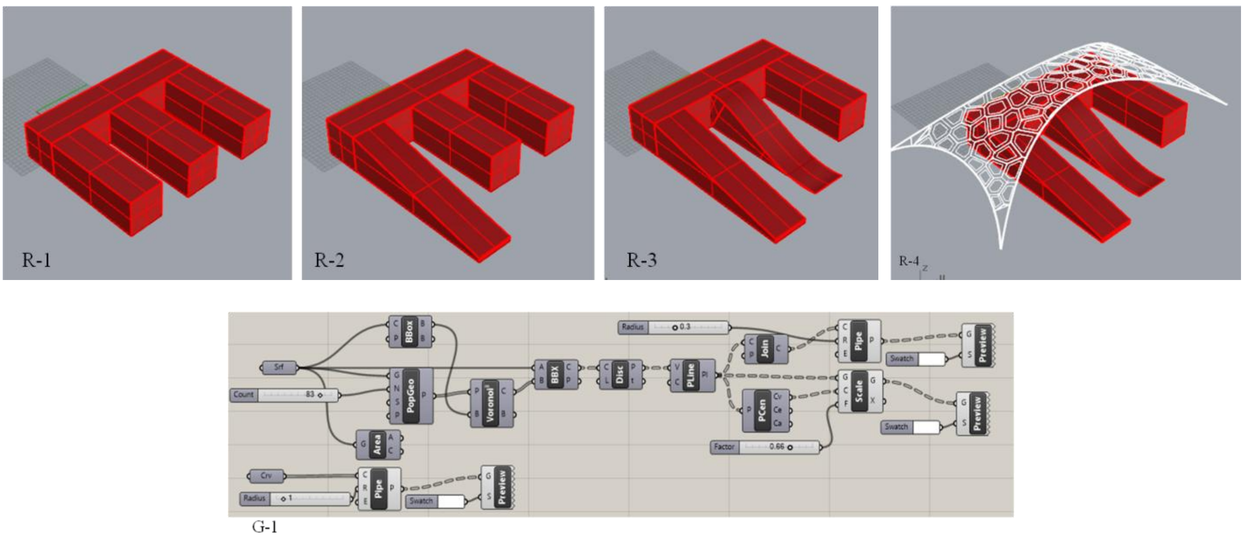

Figure 11. Alternative form generation by deformation of prime Euclidean forms, model-3

In the model we will create an alternative for; the parameters of the E type geometric plan schema are used to define the form. Like the previous implementations, the plan-type introduced in the two-dimensional environment was raised to three dimensions with the Grasshopper interface (Figure 11, R-1, G-1). The model with a block structure has many parameters. This demonstrates that there is more than one way to produce design alternatives. In order to find alternatives to the obtained typological model, the parameters will be changed (Figure 11, G-1). Deformations caused by changing the height, width, and corner axes are applicable for each block. In the next step, a linear slope is given to one branch of the model. The parameters of the two corner points of this arm that has a rectangular prism shape were created by being changed in the Z and Y axes (Figure 11, R-2). With this method, the designer can create the transformation types of the parametric model as predicted. In another alternative, a curved line is created in the model arm to obtain a wavy form. In this formation, horizontal curvilinear bending of the plane is also expressed at the same time (Figure 11, R-3). Variables in the model are corner coordinates, organic forms that can be created on the curvilinear surface, and heights.

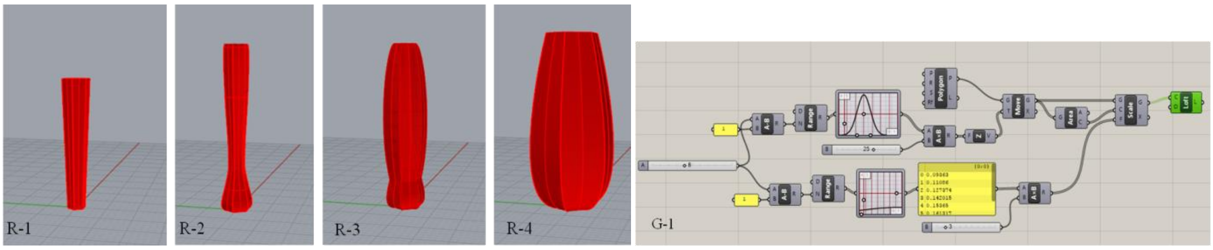

Figure 12. Alternative form generation by deformation of prime Euclidean forms, model-4

Another study for the deformation of Euclidean forms was performed on the circular plan type. The model obtained in the design field determined by defining the plan parameters was deformed through the related functions. This study focuses on alternatives where curvilinear surfaces are prominent. Deformations were obtained according to various directions in the shapes generated by keeping the plan geometry constant. Graphical values that would provide a form alternative in the formation of components and connections were given. The effect of variation in each value of these components is seen in the form. We can see alternatives that extend to the top (Figure 12, R-1), that form a node on the body (Figure 12, R-2), and that extend on one line while narrowing on the other (Figure 12, R-3). The resulting flexible forms are models based on the computational nature of the parameters. The behavior of the geometry can be changed according to the desired qualities. The basic plan geometry can be controlled without changing by changing the values of the parameters and constraints without changing.

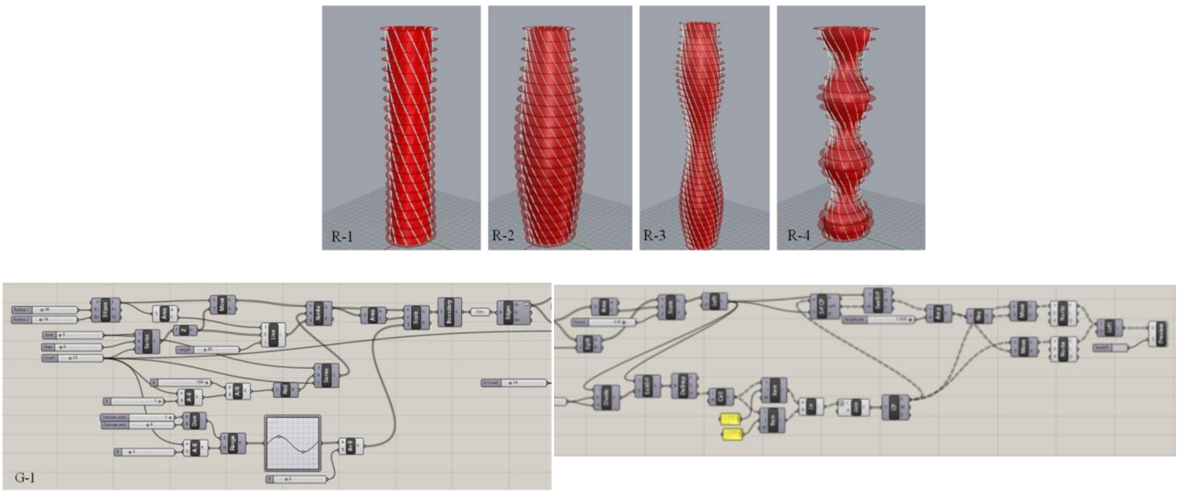

Figure 13. Alternative form generation by deformation of prime Euclidean forms, model-5

4.3. Derivation of Form Alternatives in Parametric Environment: Adding and Removing Prime Euclidean Forms

In design, it is possible to obtain free forms from simple geometric parts by operations such as merging, intersection difference. Dimensional manipulation and shape deformation can be achieved by removing free or geometric shapes from geometric forms bounded by parametric surfaces.

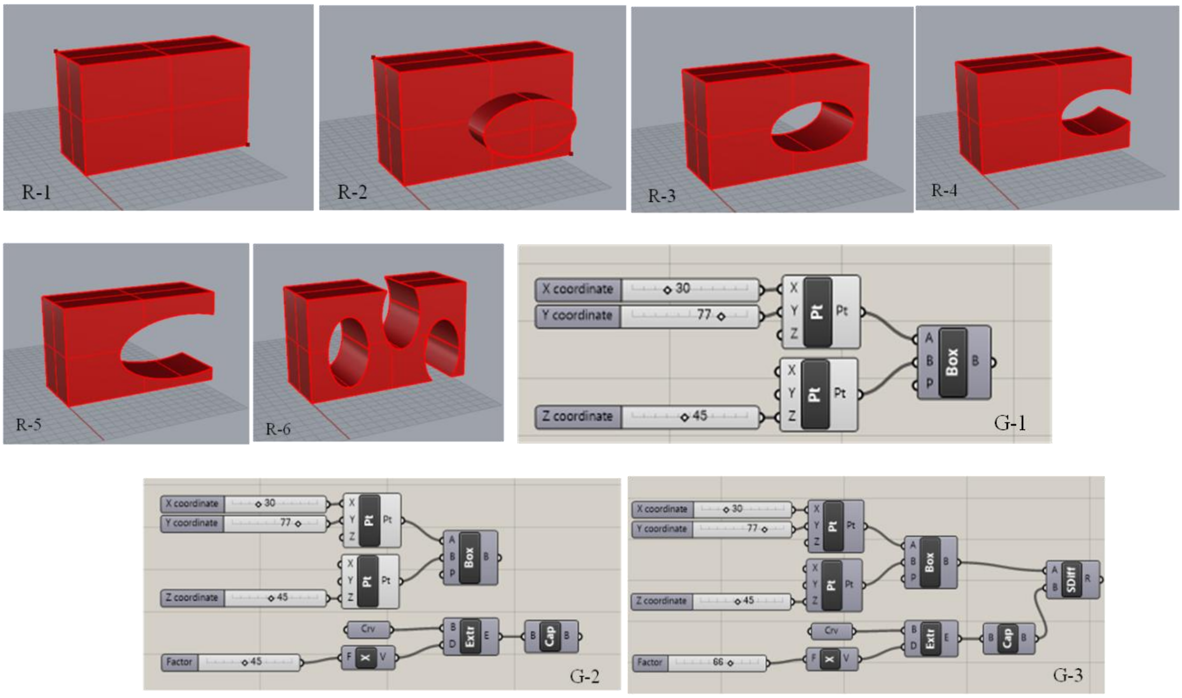

Figure 14. Alternative form generation by adding and removing prime Euclidean forms, model-5

The algorithm is defined in order to adapt to the new surface extraction operation and to create a controlled method. To do this, the geometry that will constitute the first component is created first. In this example, a rectangular linear plan form was used as the geometry component (Figure 14, R-1). In the next operation, the volume to be extracted from the main body is created. The intersection point is determined and added to the area of the original surface (Figure 14, R-2). The parameters of the parts to be affected area are created on this surface. These parameters can be the number, shape, direction, height and width of the geometry. These operations can be changed or repeated until the final product is brought to optimal conditions. Each parameter change made in these operations creates a new alternative (Figure 14, R-4, R-5, R-6). The new forms can be optimized to the original geometry thanks to these systematic algorithm networks (Figure 14, G-3), while completely different forms can also be obtained. As the generated command flow makes parameter changes possible at any stage, this change can also be valid in an operation performed on the first component while in the final step of design. The open and linked command sequence ensures that the changes made in the process without requiring a step back are reflected to the final product.

5. CONCLUSION

The study of alternatives in a design idea is the search for the best in a repetitive process. Designers have turned to design methods and tools that allow changes in the search for forms. The trend in architecture has been towards designs with a higher sense of aesthetics rather than functionality. In this formative orientation, there may be times when the functionalist structure is weak. In this study, it was attempted to obtain form diversity based on functional plan types.

Various steps are used in the digital software system to obtain form variations. In software that is frequently used in design, the successive processes can be reversed only by a certain number of processes and is done by deleting each step. This feature significantly reduces the practicality and flexibility of operations. Software programs that provide new ways of solving a problem in this sense have caused significant changes in design steps with independent operation movements. Thanks to the open command system, changes made in the previous phases can be resumed in an integrated manner with subsequent operations, making it easier and more practical to create form alternatives. In this study, a software was selected for the generation of form alternatives by taking into consideration the functions we mentioned. This was Grasshopper software which provides great convenience in terms of functionality and flexibility.

In this study, we have separated infinite form variations that can be obtained with these methods into three types based on basic formation. Alternative forms have been derived for form generations explained under the headings of form generation by horizontal curvilinear bending of the plane, deformation of prime Euclidean forms, and addition and subtraction from prime Euclidean forms. In this sense, methods were developed for occupational applications by creating alternatives that have a functional quality and fit the current understanding of form.

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