A GENERATIVE APPROACH IN DIGITAL ARCHITECTURE BASED ON TOPOLOGICAL DESIGN

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ABSTRACT
Thanks to the significant changes experienced in architecture at the end of the 20th century and the beginning of the 21st century, numerical algorithms and computational models entered the field of design and a new horizon opened for architects. This new world of architecture not only transformed the design process but also led to the discovery of new methods for design production. In contemporary architectural design, digital media has been increasingly used not as a representational tool for visualization, but as a generative tool for derivation and transformation of form. Approaches of computational and digital architectures to the design problem can be described as deductive and inductive. In the first, a transformation is applied to an object whose result is known. In the second, it is possible to reach the unknown from the data in order to obtain a certain result. Digital modeling software offers a rich repertoire of transformations that a designer can use to further explore the formal potential of an already designed geometry. The end product is topologically the same as the form before deformation. The concept of topology has an important potential for the formation and transformation of form in architecture. The aim of this study is making conceptual analysis of topological design included in the recent design parameters and discussing its place in contemporary and future architecture through architectural examples. In this context, firstly a literature study was conducted, the examples of topological design processes reflected in today's architectural discipline were examined and the results were evaluated.
Keywords: Computational Design, Digital Architecture, Parametric Design, Topological Design, Productive Approach

1. Introduction

According to Merriam-Webster and Oxford English Dictionary, topology, which is defined as a branch of geometry that deals with the study of spatial relations and the properties of geometric shapes that remain unchanged under elastic deformations such as flexion or bending, is derived from the Greek words τόπος (place) and λόgος (science, knowledge). 'Topology', in other words, 'tire geometry' is the geometry of non-angular shapes and deals with flexible forms; In this respect, it differs from Euclidean geometry, which deals with solid forms.

Geometry has always been directly related to architectural thinking styles through the problems of conceptualization, representation, construction and technology in architecture. With a historical view of these two disciplines, it is possible to perceive the direct effects of geometry on architectural creative concepts, formal features of architectural works, structural features, and building methods in architecture. Thus, architecture and geometry have a common history and their relationship predates the use of digital and computer technologies in architectural theory and design. However, the emergence of mathematical topology in contemporary architecture is linked to the increasing use of digital and computational tools in the design process. The topological design was defined by Kolarevic (2000b) as one of the computational and digital architecture methods.

Computational design gained its current conceptual meaning with the influence of the modernist thought and discoveries of the 1960s. With the introduction of the computer in design, calculation features have been started to use and some applications are called computational design. It was first used in areas such as artificial intelligence, cybernetics, industrial design, film and music industry (Akipek and İnceoğlu, 2017; Papamichael & Protzen, 1993; Simon, 1969; Wiener, 1948). CRAFT, an algorithm-based system that uses heuristic methods to optimize spatial location models for physical facilities such as production facilities, was the first application (Armor & Buffa, 1963, 1963).

Ivan Sutherland's thoughts on design diversity, constraints and parametric examples, influenced the transition to computational design in architecture. Sutherland also introduced the Sketchpad program, which is the ancestor of CAD (computer-aided design) tools, in 1963 (Sutherland, 1963; Ahlquist & Menges, 2011).
The first attempts to combine architecture and computational design were made in the 1970s. In the 1980s, computational design became known and available in architecture thanks to the commercialization of CAD (Computer-Aided Design) and BIM (Building Information Modeling) supported design tools (Koutamanis, 2005).

Since the automation of repetitive tasks increased the productivity of architects throughout the 1990s, the popularity of CAD software has increased considerably. In the 2000s, these techniques applied in the architectural design exceeded the automation of draft tasks (Terzidis, 2004). Recently emerging design approaches; have integrated different computation-based techniques such as building simulations, evolutionary optimization and new production methods with the design process (Oxman, 2017). The popularization adventure of computational design over time has caused a transformation in traditional design processes. The old design concept was based on manual drafting in the design process. Today's computational design concept has challenged and renewed old architectural design acceptances and professional practices (Rocker, 2006).

The expansion and development of digital tools and the increasing usage of computational design methods have taken place simultaneously. Although the use of digital tools such as computer programs is referred to as digital design and the use of computation to improve design is referred to as computational design in general, these two concepts have been intertwined in the process. It is not possible to evaluate the two methods separately.

There are two perspectives on computational design. While some authors consider it as an approach based on the use of digital tools such as CAD programs to develop design solutions (Alfaris, 2009; Knight & Stiny, 2015; Stiny & March 1981), others think that it is an application that uses all the capabilities of the computer in the design process. Computational design is defined as a holistic process that takes the final result by using digital tools that benefit of the computer's computational capabilities, besides that using the computer as electronic drawing boards (Albayrak, 2011; Cagan et al., 2005; Humppi, 2015; Oxman, 2017; Peters, 2013. Terzidis, 2006).

Digital architecture and design have been seen by some as an approach where tools such as computer-aided design programs are used, and decisions are made through three-dimensional models, not sketches in the design process (Turan, 2009; Marx, 2000). The possibilities provided by digital methods have been defined by some as computational, productive processes used in formation and transformation, beyond being presentation tools (Kolarevic, 2003).

Computational and digital architectures have two types of approaches to design problems: from specific to general or from general to specific. In the approach from general to specific, the transformation is made on a known object. In the other method, an unknown result is tried to be reached by using the data (Chokhachian, 2014). With digital modeling tools, potential forms that already designed geometries can be transformed are investigated.
Deformed forms and end products are topologically identical. The concept of topology offers an important potential in architectural formation and transformation.

Today, digital architecture has more than the representatively used possibilities for visualization and is used effectively not only in the architectural design process but also in the architectural production process. The predictable relationships between design and representations have been abandoned in favor of computationally generated complexities. Consistent, continuous and dynamic designs have replaced the static norms of traditional processes. Complex curvilinear geometries have been produced with the same ease as Euclidean geometries of planar shapes and cylindrical, spherical or conical forms. The aim of this study is to make a conceptual analysis of topological design that is among the new design parameters formed recently and to discuss its place in architecture by examining architectural examples.

2. Topological Design and Applications in Architecture

According to its mathematical definition, Topology is a branch of science that studies geometric forms that are not affected by changes in size and shape and remain unchanged after elastic deformations such as flexing and bending. In order to understand the topology simply, a rubber sheet example is given. Accordingly, the surface on which the geometric object is located is considered an elastic sheet. It is possible to extend, stretch or loosen this sheet as much as desired, as long as it is not folded and torn. During this process, each new shape that the geometric object will be transformed is a topologically transformed state of the other (Yaşayan, 2001).

This transformation, which is made by pulling and expanding or crushing and shrinking without tearing and cutting, is called "homeomorphism". A circle and an ellipse or a square and a rectangle can be considered topologically equivalent because both the circle and the square can be deformed by stretching them to an ellipse or rectangle. A square and a rectangle have the same number of sides and the same number of corners and therefore they are topologically identical or 'homeomorphic' (figure 1). This quality of homeomorphism is particularly interesting because it focuses on the relational structure of an object, not the geometry, the same topological structure can manifest geometrically in an infinite number of forms. In topological transformations, geometric shapes are transformed completely independent of their metric properties (Yomralıoğlu, 2000).

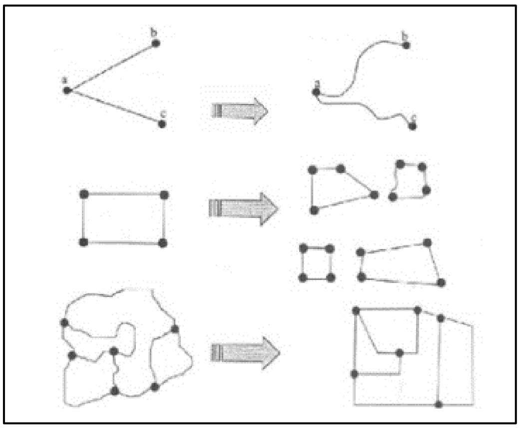

Figure 1. Topologically equivalent shapes (Karaş and Batuk, 2005)

'Topological transformations' affect the relational structure and thus the forms that emerge. For example, a rectangle can be transformed into a triangle by deleting one of its corners in a single topological operation. In all topological transformations, closed shapes retain their closed properties. The changes of the shapes do not lose their topological properties. As a simple example, we can show that a square is topologically equivalent shapes to a circle (Figure 2). The properties protected here; the feature of being closed is that the points on the shapes continue to be sequences and shapes that do not cut themselves. The changing feature is the lengths.

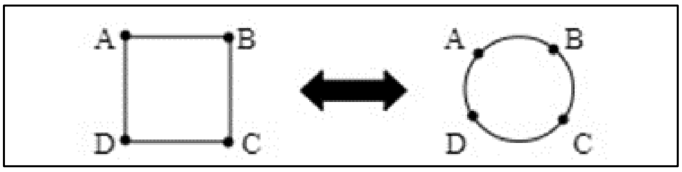

Figure 2. Topological transformation of square and circle (Karaş and Batuk, 2005)

A typical example of this is that the outer surface of a coffee mug with a handle is the same in some sense as the outer surface of a torus (bagel form). If the coffee mug was made of wet clay, it could easily bend, rub and flat the remaining part without changing the handle and the whole cup could be put into a torus form (Figure 3) (Tarım, 2006).

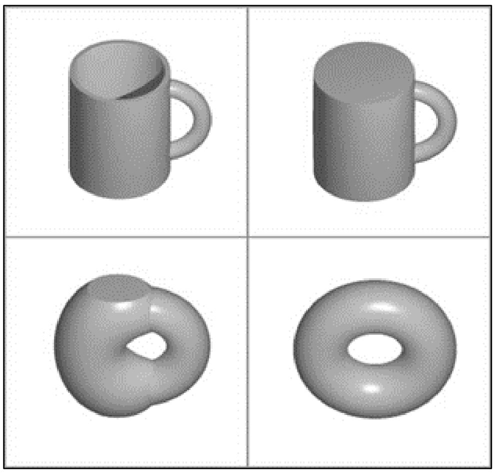

Figure 3. Mug-torus transformation as a topological shape

One of the first shapes that comes to mind when "topological form" is mentioned is the Möbius Strip. Möbius strip is the surface obtained by bending one end of a geometrically long strip 180 degrees and joining it with the other end. It was first described in 1861 by Johann Benedict Listing. A normal strip has two sides, while a Möbius strip has only one side In other words when starting to move from a point on the Möbius strip, the whole area is scanned, and the same point is returned (Figure 4).

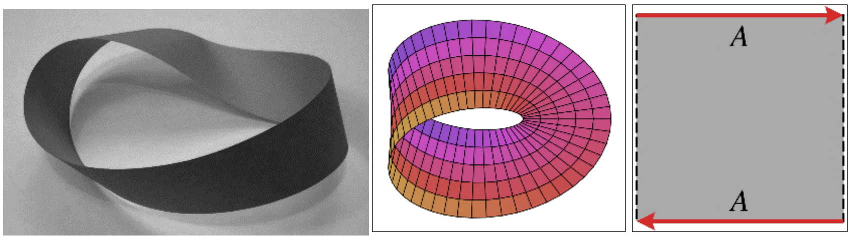

Figure 4. Möbius Strip

There are two different uses of topology in architecture: the topological understanding adopted by some philosophical and theoretical writings; topological optimization approaches that are seen with the emergence of topological tools used in drawings and models. In addition to the usage of digital techniques in contemporary architectural designs, the views of philosophers and theorists such as Gottfried Wilhelm Leibniz and Gilles Deleuze have also played an important role. The view of philosophical creativity, which supports the creation of new concepts through experimental thinking, instead of describing known phenomena, formed the basis of Deleuze's theory. Thanks to its close relationship with experimental thought and scientific knowledge, this thought has established a connection with topology and mathematics and has acquired a spatial quality. The contrasts such as small-large, discontinuity-continuity, metric-topology and fold-roughness have been explained. Deleuze not only made conceptual interpretations about topology but also made this concept accessible to everyone. He used spatial properties to interpret the problems in social and individual relations. In this respect, it has been accepted by architects who oppose the linear causality of design in contemporary works in architecture (Lojanica and Dragisic, 2018).

In his essay on "Architectural Curvilinear", Greg Lynn has presented examples of new design approaches that break away from deconstruction's "conflict and contradiction logic" to develop a "more fluid connection logic".
This new "connection fluidity" has introduced the concept of "folding", a design strategy that uses the "rubber plate" geometry of volumes, curves and surfaces separated from the Euclidean geometry represented in Cartesian space and the concept of topological form. The "folding" as defined by Deleuze has introduced a post-structuralist concept of space "consisting of platforms, cracks, folds, fillings, surfaces and depths that completely displace our spatial experience. "Folding" has become a new and distinctive "formless architecture" that questions the current concept of built-in space, its aesthetics and usefulness (Lynn,1993).

Thanks to the great transformations in architecture at the end of the 20th century and the beginning of the 21st century, changes can be made in drawings in a faster and easier way with the use of digital technology. Due to different computer software, the design and analysis process can be carried out together. Architectural design and Topology which is a branch of mathematics and, have been combined in various ways, with computer systems, CAD software and compatible plug-ins that can produce a large number of alternative designs.

The topological approach or deformation in architecture is the architectural trend that carries the traces of deconstructivism, is based on contemporary computer animation techniques and gives flexibility and plasticity to the architectural form. Reproducing the dynamic derivatives of the form depending on computer technologies is the main activity of the topological approach in architecture. Topological forms with complex geometries used in architectural design offer architects a more controlled process for the realization of the design. Because the computer software used in the construction of a structure with complex forms is based on a formal and algorithmic structure, it also brings with "process control". The transformation of the design into production depends on data transfers in this process (Tarım, 2006). The forms used in architecture in traditional design consist of simple objects such as cylinders, pyramids and spheres in Euclidean geometry. However, in recent years, architects have begun to focus on designs in more complex forms. Architectural forms within the scope of topology do not belong to Euclidean geometry (sphere, pyramid, cylinder ...), but they belong to a new understanding of mathematic such as topology and vector geometry used in the digital world (Kolarevic, 2003).

The place of topology in the design process begins in the early stages of the project and continues until the emergence of the final product. Topological optimization in architectural design is a series of methods used to select and optimize the final product in the final stages of the digital process. The topological design optimization approach is used together with computer-aided design systems for determining the optimal structural model that can be used for post-design operations (Figure 5). The basic logic of topological optimization, which has been widely used in recent years as a structural optimization method, is based on the principle of discharging material from certain areas as a way to increase the strength of the part to be optimized without any change of outer dimensions. The aim of topological optimization is to find the best material distribution that maximizes stiffness or natural frequency. The Homogenization method used for the solution of topological optimization problems was developed by Bendsoe and Kikuchi in 1988. The density method that is another method commonly used for the solution of topological optimization problems is R.J. Yang and C.H. It was developed by Cuhang in 1993 (Öztürk and Kaya 2000).

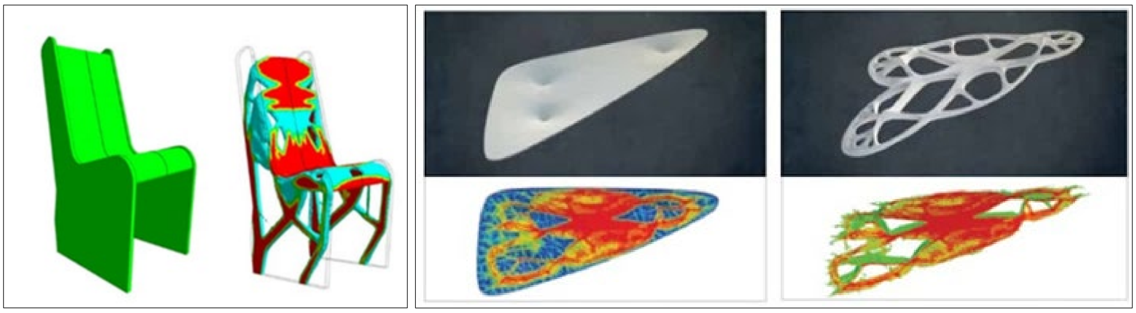

Figure 5. Examples of topological optimization

3. Case Study: Examples of Topological Architecture

3.1. Heydar Aliyev Center

Heydar Aliyev Cultural Center that built by Zaha Hadid Architects in Baku, Azerbaijan is an example of topological design with its shell structure (Figure 6). The fluid form of the building consists of a single *topologically deformed* surface where the floor transforms into a wall and then a ceiling (Figure 7). The design of the shell was inspired by the rise of the Caspian Sea in Azerbaijani mythology (Figure 8).

Figure 6. Heydar Aliyev Center

Figure 7. Heydar Aliyev Center's topological deformations

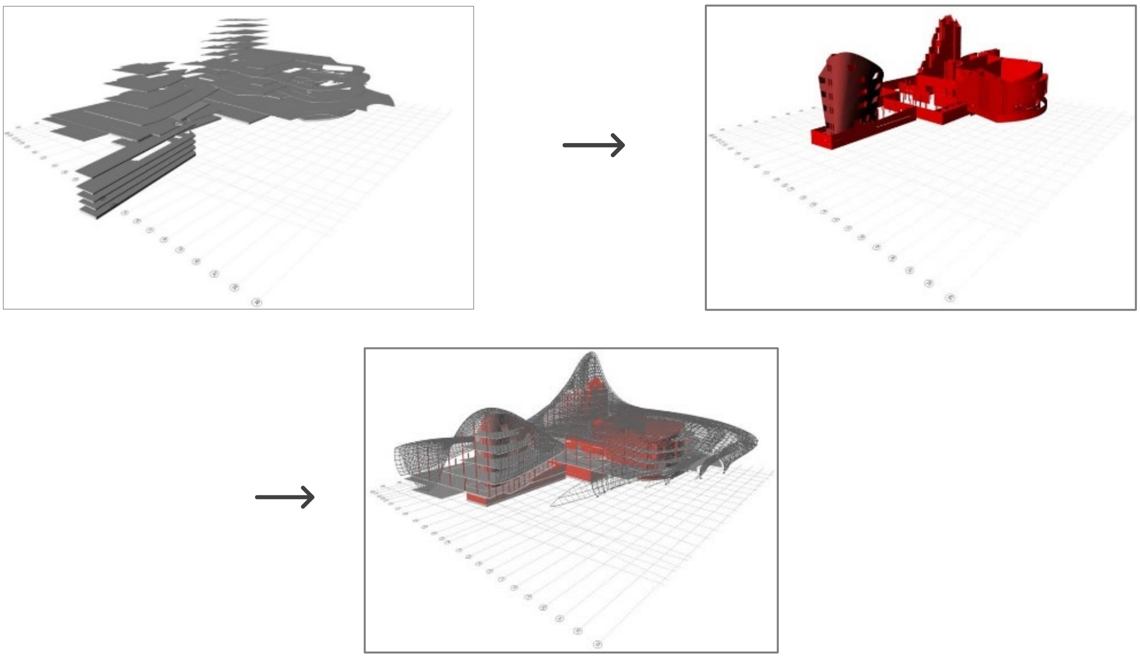

Figure 8. Heydar Aliyev Center's structural development diagram

3.2. Mobius House

The starting point of the building designed by Stephen Peralla and Rebecca Carpenter is the Mobius strip that is a topological form (figure 9). Topological architecture is used in both the organizing of the program and the form of the building. The building near Amsterdam describes a topological cycle with its curved shape and intersections made at different angles in nature (Figure 10). After the Mobius strip is made three-dimensional, the starting point for the building has been obtained.

Figure 9. Mobius House

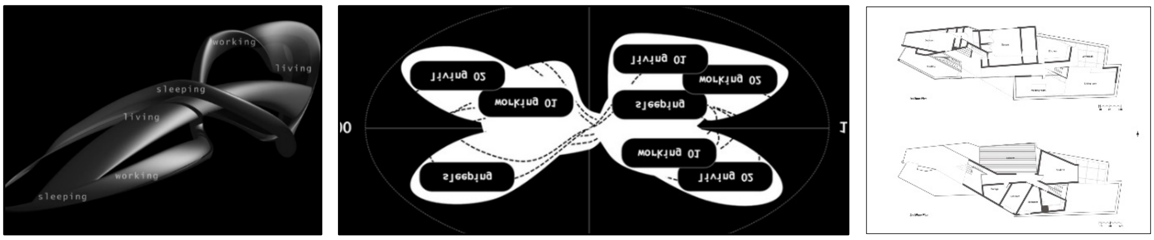

Figure 10. Mobius House concept diagram and plan diagram

This building's program is combined in a loop without using any connection points just like the Mobius strip (Figure 11). The floor plan, circulation and structure are integrated.

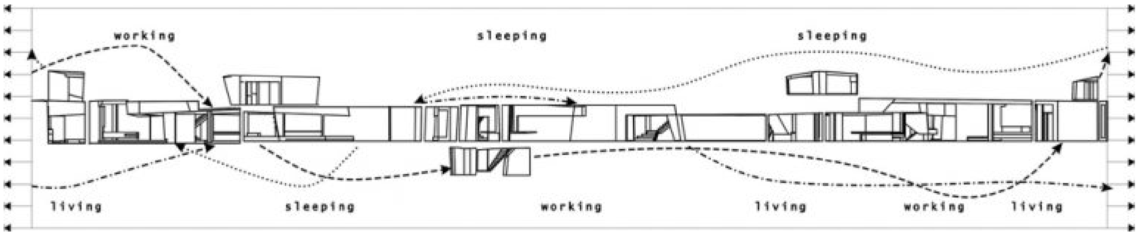

Figure 11. Loop diagram

3.3. London Aquatics Centre

The starting point of the geometry of the London Water Sports Center obtained by the topological method is the fluid form of the water in motion. It features spacious venues that open to the view of London's Olympic Park (figure 12).

Figure 12. Views of London Aquatics Center

The top cover, which has a remarkable design and provides the structure with its unique character, is a *topologically deformed* surface element (Figure 13). Covering a large area, this wavy top cover not only covers the halls where the pools are located but also functions as an eave over the main entrance coming from the Stratford City Bridge.

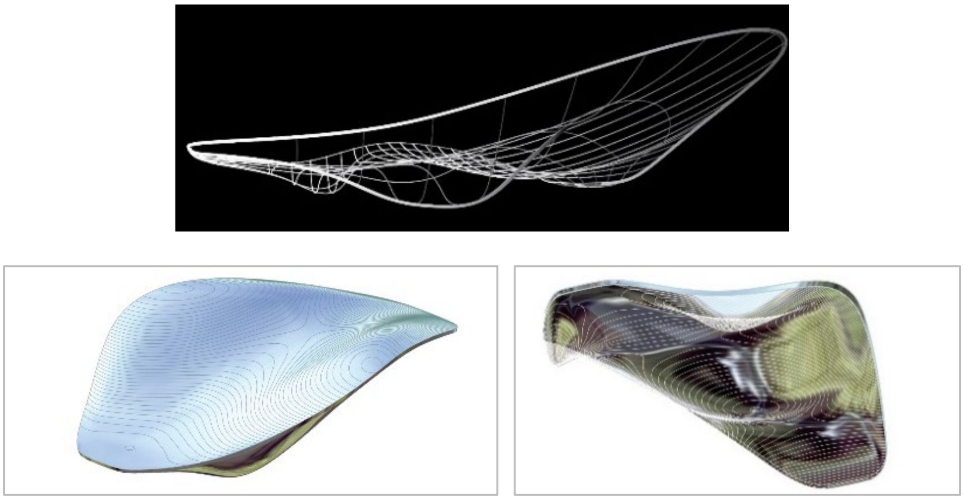

Figure 13. Concept and design of the London Aquatics Center's shell

3.4. MoPOP (Museum of Pop Culture)

The starting point of the Experimental Music House's *topologically deformed* form is the crumpled papers thrown into the trash of a guitar store near Gehry's office in Santa Monica. Its interior parts are divided by curvilinear walls called 'Snakewall' (Figure 14). Although approximately 100 physical models were made for the structure, three-dimensional modeling techniques and computer software were used to develop the final product.

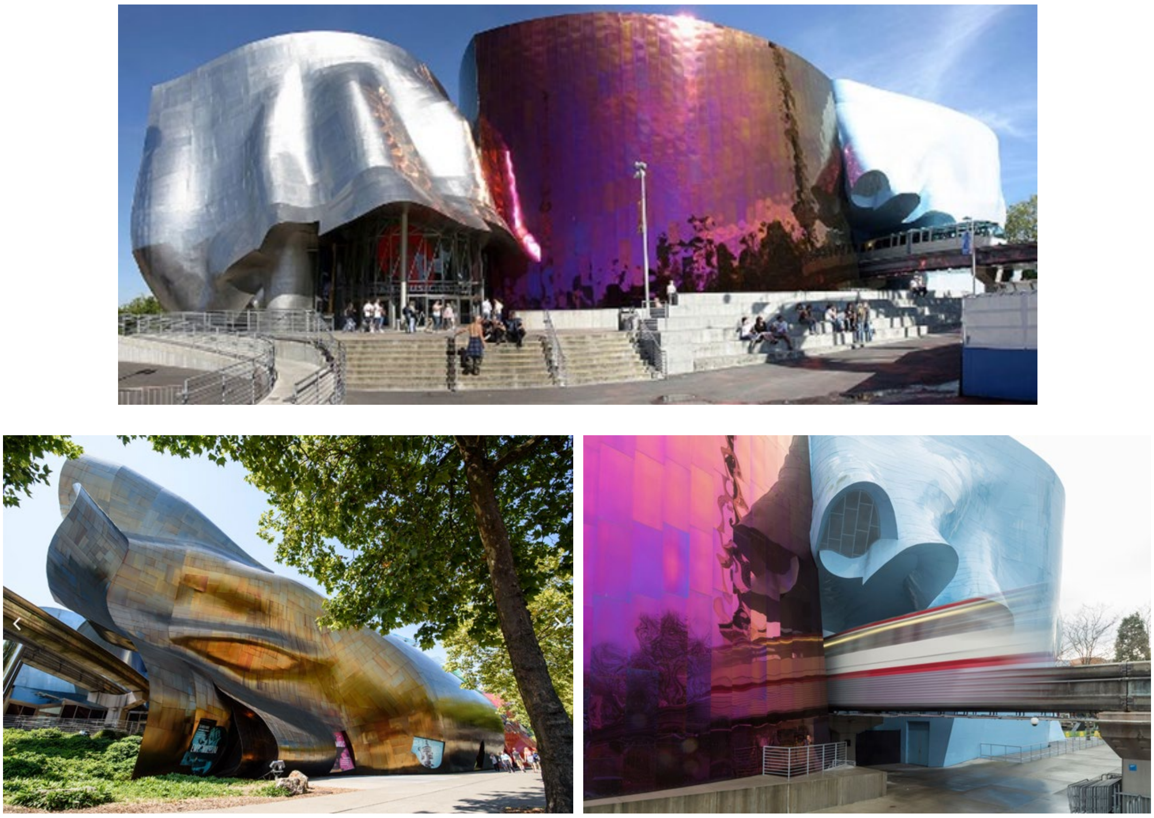

Figure 14. Views of MoPOP (Museum of Pop Culture)

3.5. Harbin Grand Theatre

The Harbin Opera House, built by the MAD group, which won the international competition within the scope of Harbin Cultural Island in 2010, has been integrated with the wetlands of Harbin. It was designed with the desolation and cold climate of the city in the north in mind. The building is in harmony with its surroundings and topography with its sculptural and monolithic appearance. According to the MAD group that designed the building, Harbin Opera House is a transmission of local identity, art and culture. With its form created by *topological deformations*, it gives the feeling of a natural formation formed by water and wind in the wetland where it is located (Figure 15).

Figure 15. Views of Harbin Grand Theatre

3.6. Walt Disney Concert Hall

Walt Disney Concert Hall, which permanently hosts the Los Angeles Philharmonic Orchestra, is among the most important concert halls in the world with its iconic architecture and near-perfect acoustic performance. The building which has a *topologically formed* curved metal shell identified with Frank Gehry is one of Gehry's best-known works (Figure 16).

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Figure 16. Views of Walt Disney Concert Hall

The facade of the Walt Disney Concert Hall, which is vibrant, wavy and formed by the combination of different angles, based on the *topological deformation* of the surfaces, reflects the musical mobility. As in most of his designs, Gehry achieved the final shape of WDCH by drawing sketches and making three-dimensional paper models. The unusual curved shape of the building has been produced with a structure fiction developed specifically for this extraordinary design.

3.7. The Hotel Marques De Riscal

Gehry, who uses curved metal installations created with *topological deformation* with titanium and steel materials on the exterior of this hotel, which was built in place of a 150-year-old stone winery, wants to make the hotel more visible with the reflections of the sun and moonlight (Figure 17).

Figure 17. Views of the Hotel Marques De Riscal

3.8. The Fisher Center for the Performing Arts

The Fisher Performing Arts Center is the latest building to be added to the Bard College campus. The building, which has a curved façade consisting of a *topologically deforme*d surface designed by Gehry, is located at the foot of the Catskill Mountains (Figure 18).


Figure 18. Views of the Fisher Center for the Performing Arts

The Fisher Center for the Performing Arts demonstrates Bard College's commitment to the performing arts as an educational and cultural necessity. The center's interesting programs and facilities provide an exceptional environment for creativity to be realized, learned and experienced. The center is named after Richard B. Fisher, former chairman of Bard's Board of Trustees.

3.9. Lou Ruvo Center for Brain Health

Designed as a building that people want to visit, remember, talk about and enjoy, the first goal of Lou Ruvo Brain Health Center is to preserve memory, and the second is to create memories. In line with these objectives, the Center designed by Frank Gehry by *topologically bending and transforming* consists of two separate buildings connected by a courtyard (Figure 19).


Figure 19. Lou Ruvo Center for Brain Health

The first building of the facility is a fully equipped service building aimed at preserving memory with both administrative offices and health research and clinical operations. The second building is the Life Activity Center building, which is reached by passing through a covered passage made of curved stainless-steel forms and illuminated by natural light from 199 windows. The building is designed as a truly unique event space to create memories with its design (Figure 20).


Figure 20. Entrance facade of Lou Ruvo Center for Brain Health

3.10. Guggenheim Museum Bilbao

Guggenheim Museum Bilbao is a modern art museum located in the city of Bilbao, in the Basque Country region of Spain. The museum situated on an area of 11,000 square meters is one of the five museums of the Solomon R. Guggenheim Foundation. The structure, dominated by curvilinear forms formed *by topological deformation*, was designed by Frank Gehry (Figure 21).

Figure 21. Views of Guggenheim Museum, Bilbao

4. Conclusions

With the industrial revolution, increase in the use of iron and steel, developments such as mechanization and mass production have affected the structure of society and the architectural discipline that interacts with it. The architecture was introduced to the technology of the age, constructing large-span structures became easier, new materials and new structural systems were started to be used.

After the industrial revolution, which is accepted as the first milestone in architectural design, the second milestone was experienced with the spread of computer technology and the introduction of computers into architectural design. The changes that started with the introduction of the computer into the design at the end of the 20th century and the beginning of the 21st century evolved from the two-dimensional designs of Sketchpad to three-dimensional designs in the 1960s. Thanks to the artificial intelligence studies carried out by Alan Turing in the 1980s, changes have continued with the merging of the concept of three-dimensional space, which is today's design concept, with computer technology.

In the traditional design process, the visual thinking method, which consists of putting the thoughts in the mind on the paper through representations, has been replaced by digital continuity with the introduction of computers into the design. Digital continuity refers to the intertwining of processes separated as design-representation-application in the traditional process in the digital design process.

In computer-aided design the design information transferred from the file to the factory with CAD / CAM technology has made architectural designs manufacturable. In addition, computers have brought the ease of producing curvilinear shapes with complex geometries, which are difficult to develop in the traditional representation environment, to architecture. Unlike the traditional design process based on representation and imagery, computers carry out operations based on numerical parameters and algorithmically defined relationships. After that, studies in the design field have progressed from making a form to finding form. As a result of all these developments, a new language has begun to emerge in architecture. Architecture with complex geometries, dominated by a flexible space understanding with curvilinear and fluid lines, has begun to be adopted as a contemporary architectural language.

The concept of topology in architectural design has made the dynamism and flexibility in the new spatial concept identifiable with subforms such as blob, bleb, and fold. As a result of this study, it was concluded that the concept of topology cannot be reconciled only with curvilinear forms, it is a phenomenon that includes concrete and abstract data that expresses the whole design knowledge rather than the formal meaning.

Topological optimization in architectural design is the last step to optimize the product obtained at the end of the digital design process in line with criteria such as function, cost, aesthetics, durability, acoustic value, and light. The concept of topology emerged as a result of the introduction of computer-aided design into architecture, and its effects on architectural design have been revealed with examples.

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